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"Dinosaur Provincial Park represents the most important remaining fragment of the dinosaurian world known to mankind."

Dr. Dale A. Russell, chief of the paleobiology division of the Canadian National Museum of Natural Sciences, Ottawa, in a written statement on the scientific significance of Dinosaur Provincial Park in southern Alberta.

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FIELD TRIP 10

SEDIMENTOLOGY AND PALAEONTOLOGY OF THE UPPER CRETACEOUS JUDITH RIVER/BEARPAW FORMATIONS AT DINOSAUR PROVINCIAL PARK, ALBERTA

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FOREWORD

The Tyrrell Museum of Palaeontology in Drumheller, opened by Alberta Culture in September 1985, has a mandate to collect, research and present fossil evidence for the history of life on Earth, with particular emphasis on the unrivalled fossil record of dinosaurs in Alberta. The public gallery of 4400 sq.m. takes the visitor on a walk through evolutionary developments by means of 800 specimens, dramatic murals, interactive displays, mini-theatres, computer games, a window into the fossil preparation laboratory, as well as a conservatory and several aquaria which house 'living' fossils of plants, trees and freshwater life. Research programmes include both vertebrate and invertebrate palaeontology, palynology, taphonomy and sedimentology. Research conferences are hosted annually. Public activities feature guided tours for school groups by advanced booking, free weekend film and lecture programmes, and a volunteer programme to assist excavations in Dinosaur Provincial Park. Apart from the galleries and research quarters, facilities include a 45,000 volume library, a computerized collection of 80,000 fossil specimens, a 200-seat auditorium, a large cafeteria and trail walks in adjacent badlands.

The satellite Field Station in Dinosaur Provincial Park, opened by Alberta Culture in May 1987, exhibits the knowledge of local ancient environments in a 250 sq.m. gallery. In addition, it contains on-site preparation and research facilities to support annual fieldwork programmes.

Further information may be obtained by writing the Tyrrell Museum of Palaeontology, Midland Provincial Park, P.O. Box 7500, Drumheller, Alberta, T0J 0Y0, or phoning (403) 823-7707.

1.0 INTRODUCTION

Along the Western Interior of North America, the late Jurassic to Paleogene stratigraphic record of foreland molasse wedges intercalated with epeiric marine episodes (Fig. 1) has been the subject of an enormous amount of geologic attention over the last century (Porter et al., 1982). Perhaps no other geologic province in the world has stimulated such a massive volume of inter-disciplinary literature that is so well communicated across an international border (Caldwell, 1975).

An intensive search for hydrocarbons and regional surface/subsurface stratigraphic work occurred in the wake of early geologic mapping. This pre-1950 body of literature was followed by a growing series of site-specific studies. Sedimentological interest accelerated during the 1970's and particularly in the present decade, due partly to a rejuvenated interest in coal resources and further recovery of hydrocarbons. The Alberta segment of the Western Interior (Fig. 2) has shared in these research trends, due especially to field excursions run in conjunction with the 1982 AAPG/SEPM Calgary meeting, the 1982 IAS Congress in Hamilton, and the 1983 CSPG Mesozoic Conference.

Dinosaur Provincial Park (Fig. 3), contains excellent badlands-type exposure of the Upper Cretaceous Judith River Formation and transition to the overlying Bearpaw Formation. The Park attained major status in 1979 as a UNESCO World Heritage Site (joining the company of such other places as the Grand Canyon, Florida Everglades and the Great Barrier Reef), and was nominated in 1984 as one of the hundred best geological sites in the Rocky Mountain Section of the GSA, as part of their Decade of North American Geology

project. The UNESCO designation reflects the fact that Dinosaur Park is recognized as the world's most significant site for dinosaur fossils, in terms of overall diversity, abundance and number of articulated, museum-quality specimens (Table 1).

Excursion guidebooks normally describe a series of discrete 'stops', reflecting scattered outcrop over the region to be visited. In the extensive belt of badlands through Dinosaur Park, the quality of outcrop gives a virtually continuous display of facies and 3D geometry of successive units. Given this rather unique feature, the control by weather conditions on access to most areas, the experience with past field trips in the Park (Koster, 1983, 1984) where exposures along hikes to prescribed 'stops' have created as much interest as the 'stops' themselves, and the restriction on public access to all but a small central region of the Park, the last part of this guidebook edition (cf. Koster, 1984; Koster and Currie, in press) gives only a general summary of the features to be visited. This is preceded by both a regional and detailed local view of molasse sedimentation of Campanian age in Dinosaur Provincial Park. In turn, this provides a context for paleontological sections.

It is intended that by running another excursion to the Park further light will be shed on evolving interpretations of stratigraphic, sedimentological or paleontological features. Participants are therefore encouraged to contribute their ideas to the discussions at outcrop and in other opportunities during the excursion. Your interest and input will be very much appeciated.

2.0 DINOSAUR PROVINCIAL PARK

2.1 Introduction

The term 'badlands' was first used in North America by early French trappers who described the semi-arid, rocky terrain along the White River in what is now South Dakota as the 'mauvaises terres' (Beaty, 1975a). Traditionally, the Drumheller area is Alberta's best known area of badlands because the town is a popular tourist stop, now with the Tyrrell Museum of Palaeontology, on the major route linking Saskatoon on the Yellowhead trail with Calgary and the TransCanada Highway. As the Red Deer River flows south-eastward from Drumheller perpendicular to the strike of the Alberta syncline, it descends stratigraphically from the Horseshoe Canyon Formation through the Bearpaw Formation into the Judith River Formation of Campanian age.

2.2 Location and Access

Along the Red Deer River, 40 km northeast of Brooks, an oil and agricultural supply town on the TransCanada Highway 190 km east from Calgary, lies Dinosaur Provincial Park (Fig. 3). Located in the heart of the largest and most impressive expanse of badlands in Alberta, exposures in the Park are distributed along a 23km reach of the river locally extending up to 5km away from the banks, for a total area of approximately 75km^2.

The primary access route to the Park is north onto Highway 873 from the TransCanada Highway at Brooks. Park signs are located at the subsequent turns onto Highways 544 and 551. The final part of this 48km paved route leads along a narrowing prairie divide between Deadlodge Canyon and the coulee of Little Sandhill Creek. Before the steep 80m descent through badlands to the alluvial flats of the Red Deer River, the parking lots near the Park gate are spendid viewpoints over the expanse of badlands. The Park campground, Tyrrell Museum Field Station, and other visitor services lie approximately 1km northeast of this point where Little Sandhill Creek joins the river.

The nearest bridging points across the Red Deer River are at Steveville (a former village and ferry point) on Highway 876 at the western Park boundary, and 30km east outside the Park on Highway 884 north of Jenner. Other grid roads serve to enclose the Park across the prairie to north and south. Badlands lying elsewhere can be reached by a number of remote tracks (ranch access or petroleum industry service roads) passable only in dry ground conditions. Without a Research and Collection Permit from Alberta Recreation and Parks or the company of an authorized person, entry to badlands within the Park's Natural Preserve (outside of the area immediately surrounding the public campground) is prohibited.

2.3 Badlands

2.3.1 Holocene Developments

In a proglacial setting that postdated the youngest drift sequence, about 13,000 yrs. B.P. (Westgate, 1967), glacial diversion near the town of Red Deer of the former headwaters of the Battle River led to the development of a spillway, now the Red Deer valley (Bayrock and Broscoe, 1972). Probably of a catastrophic nature (Kehew, 1982; Bryan et al., 1987), the Deadlodge Canyon reach was deeply eroded from prairie level at ca. 705m locally to 620m a.s.l. McPherson's (1966) boreholes in the local floodplain record subsequent alluviation to the 635m level. Across the typically 700m wide valley floor, lines of cottonwood and other arborescent flora delineate subtle scroll-bar relief between the slightly sinuous modern channel (sinuosity ca. 1.1, wavelength ca. 3.5km) and coulee walls. Channel migration, up to 250m since the 1880's (McPherson, 1966) is mainly translational producing lens-shaped point bars that shifted incrementally downstream prior to flow regulation in the upstream part of the Red Deer River basin.

The preglacial Bow Valley, occupied now by the Bow River west of Bassano and by the Red Deer River east of Jenner lies to the north of Deadlodge Canyon (Stalker, 1961). However through the Park area, bedrock joint sets trending parallel and perpendicular to the Cordillera have directed the linear course of the spillway (see Section 2.3.3). As a result of the canyon's configuration with respect to the preglacial Bow Valley, the park straddles a bedrock 'high' - a feature that favours development of badlands (Bayrock and Broscoe, 1972). This relationship is demonstrated by the absence of badlands on the opposite side of the valley from the Park entrance viewpoint where the drift sequence thickens across a tributary preglacial valley.

During the Holocene, the spillway walls have become heavily dissected due to the processes of scarp retreat, piping and pediment widening. The prairie edge is now farthest from the main valley line where the drainage density of joint-controlled tributary coulees is greatest. Although Holocene climatic change has undoubtedly varied the rate of badland development, measurements show that modern scarp retreat proceeds at 1-2cm/year (Bayrock and Broscoe, 1972) with computed minimum denudation rates averaging 0.83m/1000 years (Campbell, 1970). Typically 10% of the annual precipitation arises from the heaviest summer convective storm (ibid.) causing erosion to be periodically intense.

2.3.2 Stratigraphy

Relief of badlands in the Park increases eastwards from 60-115m (Fig. 4) due mainly to a higher elevation of the prairie surface downstream. Pleistocene surficial deposits are commonly only a few metres thick, except where pre-glacial buried valleys traverse the badlands at high angle to the

modern Red Deer River. The Judith River Formation forms the bulk of the badland exposures. It is a channel-dominated coastal plain sequence richly fossiliferous with a wide variety of vertebrates (Table 1).

The Judith River-Bearpaw boundary represents a continental-marine transition separating the last two cycles of foreland sedimentation along the Western Interior (McGookey, 1972). The actual transition is conspicuously marked by a argillaceous coaly zone, up to 20m thick, correlative with the Lethbridge Coal Zone (see Section 3.6.1) that locally includes several metres of herringbone cross-laminated, greenish sandstone containing Ophiomorpha nodosa, O. bornensis and bored oyster valves (S.G. Pemberton, written communication). Profiles through this transition of palynomorphs, megaspores, dinoflagellates, forams, diatoms and sponge microfossils all show an orderly change from on-shore, through paludal and lagoonal, to shelf conditions (A.R. Sweet and J.H. Wall, written communications).

East of 472500mE (Fig. 3) above 735-740m a.s.l., the basal 25m of the overlying marine Bearpaw Formation also crops out. This sequence of concretionary fissile shales contains the ammonites Placenticeras meeki and Hoploscaphites, the ornate bivalve Cymella montanensis (W.A. Cobban, written communication), as well as shark teeth, fish scales, mosasaur and plesiosaur remains. The distribution of the Bearpaw Formation on GSC bedrock geology maps (see Section 10.1) suggests that were it not for the deeply eroded tract of local badlands, the basal Bearpaw would have concealed the Judith River Formation over the entire region.

2.3.3 Joint Control on Outcrop

A striking geomorphological aspect of the badlands in Dinosaur Provincial Park is the rectilinear pattern of drainage lines. This is an important consideration in that any recurring relationship between outcrop facies and average paleochannel directions must be established. Straight segments of drainage range in length from 9.3km along parts of the Red Deer River valley to as little as 200m in 1st order coulees and gullies. Figure 5 depicts the orientation of all obviously linear reaches (n=180) determined from a 1:30,000 air photomosaic of the Park.

Alignments of geomorphological features developed in undisturbed strata are commonly related to fracture systems. The general study of Ozoray (1972) substantiated this for the Alberta plains, although preferred coulee alignment in the Lethbridge area apparently results from chinook winds (Beaty, 1975b). In drift-covered terrain, the degree of control by bedrock joint sets on surface linear features is somewhat controversial (Babcock, 1974). However, the Park area is only thinly veneered with till, glaciofluvial and glaciolacustrine deposits - hence the ease of badland development. The Red Deer River valley, having originated as a spillway upon deglaciation, would have, in any case, facilitated direct access to jointed bedrock for headwardly-eroding tributary systems.

Babcock's (1973) study of joint orientations in bedrock across the southern Alberta plains revealed a complex pattern comprising three orthoganal systems (Fig. 6) as follows:

S_1, T_1 The predominant system striking ca.065° and 155° respectively, which both parallels structural undulations in major Phanerozoic

stratigraphic surfaces (Robinson et al., 1969), and the alignments of maximum/minimum horizontal stress with respect to the Rocky Mountain foldbelt as detected by 'borehole breakouts' (Bell and Gough, 1981).

S_2,T_2 A subordinate system S_2,T_2 striking ca.005° and 095°, respectively, roughly parallel and perpendicular to the crest of the Sweetgrass Arch (Tovell, 1958).

S_3,T_3 A local set (of uncertain cause) oriented at ca.045° and 135°, respectively, which predominates northeast of Medicine Hat.

Ozoray (1972) found that linear geomorphic features in Alberta display evidence of two structurally-controlled orthogonal systems. The first, aligned 054° and 134°, appears to be a hybrid of sets S_1,T_1 and S_3,T_3 in Babcock's (1973) study. Ozoray's second set was described as meridional and latitudinal, and thus appears to relate to S_2/T_2.

Three of Babcock's sample sites were located in badlands along the Red Deer River valley enclosing the Park. In downstream order, the mean orientations parallel 1) S_1,T_1, 2) S_3,T_3 and 3) S_1,T_1,S_3,T_3 hybrid and T_2. One joint orientation was found to predominate at each site, and this inter-site variability in joint patterns is evidently typical (Fig. 4 in Babcock, 1974). The question arises, are these bedrock joint sets replicated by the network of coulees?

Using a 10° sector scale, the rose diagram of the raw frequency data is polymodal but chi^2-test reveals that the observed pattern does not depart signficantly from a random distribution. However, weighting of the orientation data according to segment length accentuates the modes and

Stratigraphic section and correlation work in coulees should recognize the control by regional joint sets on preferred orientation of continuous outcrops. The exposures within the heavily dissected tracts of badlands at Steveville, and around the Park headquarters, are sufficiently three-dimensional that these problems are lessened. These findings have influenced the methodology of fieldwork, besides being a contribution to our understanding of the late Pleistocene and Holocene development of the badlands.

2.3.4 Hypsometry

Lastly, interpretation of the stratigraphic or spatial frequency of any data set (e.g. abundance of a paleochannel type or quarried vertebrate skeletons) must take into account the distribution of the badlands area with respect to elevation (Fig. 4). This hypsometric analysis (Strahler, 1957) has been carried out by measurement of the horizontal area falling within successive
10m elevation intervals between the floodplain and prairie limits along 20 north-south topographic profiles, 1km apart, from 456000 to 475000mE on the Mercator Grid. This data has also been grouped into the A to E 'tiers' of Beland and Russell (1978). Such area-altitude data now enables the frequency of any paleontological or sedimentological variable to be standardized in terms of number per unit area.

2.4 Fieldwork Conditions

Annual precipitation averages 32.5 cm, the wettest period being from May until September. Although the average July temperature is 19°C, daytime maximum shade temperatures commonly exceed 30°C. Since commonly there is no shade available, working temperatures may approach 50°C.

Hiking and fieldwork within the badlands requires fair weather because of the treacherous nature of bedrock and drift slopes when wet. Storm runoff is immediate, and the rate at which bedrock surfaces dry to allow fieldwork depends largely on precipitation being followed by sunny, windy weather. Colour contrasts in stratigraphic sections are inverted in wet weather, and trenching and sampling operations are impractical on damp slopes. However, heavy rain has two desirable repercussions from the sedimentological standpoint: 1) sandstone slopes are commonly stripped of their thin weathering rind to reveal sedimentary structures, that otherwise are discernible only in differentially-weathered concretionary horizons and, 2) pediments become veneered with new sediment and thus provide potential new collecting ground for fossil skeletal material.

The following precautions are advised:

1. Inform Park officials or other colleagues of your intended work area: hiking alone in the more remote areas is not advised.
2. Enter the badlands only when dry.
3. Wear sturdy boots, light-colored loose clothing and carry water.
4. Mind your step on the steeper slopes for the deep vertical 'pipes' that mark the beginning of local underground conduits for storm runoff.
5. When otherwise occupied on steep slopes, beware of sudden movements by wildlife such as deer, large predatory birds and bullsnakes - and watch out for rattlesnakes and scorpions, although relatively few are seen.

3.0 REGIONAL GEOLOGY

3.1 Stratigraphic Nomenclature

Canadian nomenclature of stratigraphic sequences bordering the Western Interior Seaway (Fig. 8) is characterized by: 1) differences across Alberta between the indurated outcrops of the disturbed belt and the less consolidated counterparts of the Plains region; 2) differences between nomenclature in Montana and Alberta; 3) differences in usage by successive workers in the same area; 4) exchange of Canadian terms with American equivalents; 5) problems in recognising outcrop-based divisions in regional down-dip subsurface studies; and 6) rejections by some workers of previously recommended refinements published in accordance with the International Stratigraphic Guide.

Earlier studies in Dinosaur Provincial Park employed the term Oldman Formation (e.g. Dodson, 1971; Beland and Russell, 1978). This nomenclature reflects the traditional usage across the southern Alberta plains in which mid-Campanian non-marine strata have been divided into the Foremost (below) and Oldman Formations (e.g. Crockford, 1949): geological maps of Alberta still reflect this tradition (see section 10.1).

Earlier work often referred to the Oldman unit as the Pale Beds (e.g. Powers, 1931). Further inconsistences arose in the work of Williams and Dyer (1930) who assigned the Foremost Beds and Pale Beds to the Belly River Formation, and Dowling (1917) who extended the base of his Belly River Series to include the Milk River Sandstone. Other early regional studies elected to recognise numerous named members in the Belly River Series or Group (e.g. Allan, 1919). For a comprehensive review of these nomenclatural problems, the reader is referred to McLean (1971, 1977). Earlier disputes over correlation

with sequences in Montana have been recalled by Waage (1975). By the turn of the century, Stanton and Hatcher (1905) had shown conclusively that the Belly River beds of southern Alberta were correlative with the Judith River Formation in Montana.

McLean's (1971, Table 2) literature review demonstrates considerable disagreement in distinguishing the Foremost and Oldman Formations. Consensus was restricted to four points, in that the Foremost sequence is generally darker, contains more coal seams, carbonaceous beds and brackish-water fossils, but less cross-stratification. Given the ideal criteria for defining a formation, and the desirability of being able to recognize a formation in the subsurface, the basis for perpetuating the Foremost-Oldman division is weak.

Powers (1931; p.84) claimed that the boundary between the Foremost and Oldman Formations is clearly defined by the Taber coal zone. However as McLean (1971; p.32) pointed out, the type locality for the Foremost in Chin Coulee (see Fig. 7) does not expose its base, or the Taber coal zone. Yet Shawa and Lee (1975) in a field guide to this locality recognized the formation boundary as being present. In the Milk River Canyon, Speelman and Hills (1980) placed the boundary at the onset of fluvial conditions above a shoreline sequence, defined primarily on the basis of megaspore paleoecology.

This part of the Upper Cretaceous succession therefore has been the subject of particularly variable and inconsistent nomenclature; all six of the opening comments in this section are pertinent. McLean's (1977; p. 1105) nomenclatural recommendations are as follows:

"....Lithostratigraphic nomenclature in the Upper Cretaceous Montana

Group in the southern Plains of Alberta is ambiguous and confusing. The names "Oldman" and "Foremost" are vague, ill-defined terms whose use should be discontinued. The name "Judith River" should be employed for the entire interval beween the Pakowki Formation below and the Bearpaw Formation above. It has been applied consistently to this stratigraphic interval in northern Montana and, at times in southern Alberta, for the past 100 years and its use would serve to unify and simplify the nomenclature throughout this area.

Use of the name "Belly River" should be retained in the Foothills of southwestern Alberta, beyond the western limit of the Pakowki Formation, where the Judith River and Milk River Formations are not differentiated...."

This series of proposals, approved by the Stratigraphic Committee of the Institute of Sedimentary and Petroleum Geology, have been largely adopted by staff at the Tyrrell Museum of Palaeontology. The term 'Judithian' has, incidentally, been in use for some time as a stage in the regional succession of mammalian faunas (Russell, 1975).

3.2 Paleogeography

The Judith River Formation represents the regressive phase of the Claggett Cycle in McGookey's (1972) terminology, and based on Walker's (1982) review appears to be synchronous with the onset of uplift and deformation east of the Omineca Crystalline Belt as far as the Front Ranges (Fig. 9). Batholith emplacement and volcanic activity in western Montana, and thrusting in the Sevier Orogenic Belt of Utah were also occurring at this time (Lerand, 1982). Each of the four coarsening-upward, marine/coastal plain megacycles of

12-17 and 12-21). Figure 10 applies to the maximum regressive phase of Judith River deposition and incorporates the paleogeographic evidence of the above-noted work, as well as the cross-sectional data of McLean (1971) and McGookey (1972). The prevailing continent-wide paleogeography for mid-Campanian time is shown in Text-figure 7 of Williams and Stelck (1975). During the Cretaceous Period, North America lay further east and was twisted clockwise in comparison to its present configuration, because of the progressive northward advance of sea-floor spreading in the North Atlantic. During the late Cretaceous, southern Alberta had an approximate paleolatitude of 57°N (Marsaglia and Klein, 1983), 6-7° further north than at present.

3.3 Seaway Circulation

Although the Cretaceous sedimentary record in the Western Interior of North America has long been the subject of intensive study, it is only since the late 1970's that attention has been given to dynamic aspects of circulation in the Seaway (Fig. 10). This trend is evident from a comparison of proceedings' volumes arising from symposia hosted by the GAC in 1973 (Caldwell, 1975) and the CSPG in 1983 (Stott and Glass, 1984). Numerous papers and abstracts in the CSPG volume interpret depositional sequences in the context of storm or tidal processes (e.g. those by Kamola and Howard, Nelson and Scott, Pemberton and Frey, Rahmani, Rosenthal and Walker, Van Hulten, and Zaitlin and Shultz), whereas only one (by Weimer and Land) is contained in the GAC volume.

In the case of storm-influenced sedimentation, only a short time has elapsed between formal identification of hummocky cross-stratification and basin-scale analyses of intense weather event (e.g. (Marsaglia and Klein,

1983). That circulation in the Western Interior Seaway was also affected by tides stems largely from a paper by Klein and Ryer (1978). However, Parrish et al. (1984) have since cautioned that a firm knowledge of tidal circulation in the Seaway awaits integration of theoretical models (e.g. Slater, 1985) with outcrop-based evidence.

In view of the present-day abundance of tidally-influenced coastal plain settings, the relatively slow rate with which ancient analogues have been recognized in the Western Interior is surprising. In part, this is attributed to the fact that since tidal circulation and storm activity act jointly in nearshore environments (viz. Reinson, 1984), their signs in the rock record may be difficult to discriminate (Parrish et al., 1984). However, cross-bed sets containing bundled mud drapes that replicate diurnal and neap-spring tidal cycles have been identified from deposits in the Western Interior Seaway (e.g. McCrory and Walker, 1986).

Intuitively, one anticipates that interaction between the tidal Seaway and distal, low-gradient reaches of the foreland drainage resulted in estuarine conditions. It is not therefore surprising that some paleochannel sequences, formerly considered to be strictly fluvial, have recently been re-interpreted. In Alberta, this has transpired for the Lower Cretaceous McMurray Formation near Mort McMurray (Carrigy, 1971; Flach and Mossop, 1986), the Upper Cretaceous Judith River Fromation at Dinosaur Provincial Park (Dodson, 1971; Koster, 1984, 1986a and b; Koster and Currie, in press) and the Horseshoe Canyon Formation near Drumheller (Shepheard and Hills, 1970; Rahmani, 1982).

Modern estuaries have been studied intensively by hydraulic engineers, biologists, etc., but there have been comparatively few sedimentological studies with direct application to interpretative work in the rock record. Fairbridge (1980) noted the lack of any comprehensive synthesis on sedimentological aspects of estuaries from the geologic perspective, although several important reviews have appeared since (e.g. McCann, 1980; Clifton, 1982). In terms of the newer textbooks in sedimentary geology, estuarine depositional systems (as defined in this guidebook) are either treated briefly as part of the maginal marine setting, or not at all.

3.4 Paleoclimate

An apparently more equable poleward temperature gradient with a concomitant latitudinal compression of high-latitude climatic belts during the Cretaceous is generally ascribed to the lower percentage of land within the subtropical belt (Thompson and Barron, 1981). Increasingly, these variables are being quantified for Cretaceous time (e.g. Lloyd, 1982), thereby allowing an independent check on local outcrop-based evidence.

For the Upper Cretaceous in southern Alberta, notably the Judith River Formation at Dinosaur Park, the following paleoclimatic evidence derives from previous work as cited.

Seasonality:

- annual rings in petrified wood (Dodson, 1971);
- growth rings in vertebrate of Champsosaurus (ibid.);
- periodic stage variation in paleochannels (see Section 4).

Moderate-high precipitation:

- Taxodioxylon wood, metasequoian foliage and Sequoites cones indicating mean annual rainfall of at least 1200 mm (Beland and Russell, 1978; p. 1019);
- inferred hebivore biomasses of at least 20t/km on alluvial soils enriched by volcanic ashfalls require mean annual rainfall of at least 1000 mm (ibid.);
- perennial flow in fairly deep paleochannels (see Section 4).

High precipitation/evapotranspiration ratio:

- frequent, widespread paralic conditions with preservation of carbonaceous mudrocks and coal;
- dense flora required for abundant herbivorous fauna preserved in Dinosaur Provincial Park (Dodson, 1971; Beland and Russell, 1978);
- absence of reports of any evaporitic paleosol types or dessication features.

Winterstorm activity:

- interpretation of hummocky and swaley cross-stratification along the coast of the Western Interior Seaway (Walker, 1982; p. 22-30) by Marsaglia and Klein (1983);
- floods in paleorivers (see Section 4).

Moderate-high temperature:

- 17-27^{o}C paleotemperatures of water in the adjacent Bearpaw Sea (Forester et al., 1977).

These numerous, independent lines of evidence collectively indicate a warm, moist paleoclimate with rather pronounced seasonality and occasional winter cyclonic disturbances. Prevailing winds were westerly (Lloyd, 1982) with the proportion of orographic to leeside (i.e. foreland) precipitation presumably increasing in proportion to the growing scale of mountainous relief along the Pacific rim. Foreland drainage was undoubtedly perennial and with

relatively high density: it also seems plausible that the main fluvial systems emerging from the front ranges received tributary input from within the foreland. The rather immature mineralogy of Belly River sandstones in the foothills (Lerbekmo, 1963) is attributed to short transport distance and their probable first cycle nature, rather than a specific climate.

3.5 Structure and Outcrop

Across southeastern Alberta, the Judith River Formation, directly underlies Pleistocene drift in a broad arcuate tract of 29,500km^2, and typically about 150km in east-west width, that has the Sweetgrass Arch structure as a medial line. The bedrock surface is traversed by a dendritic network of preglacial valleys (Stalker, 1961).

The Red Deer River valley forms a northern limit, and along the Saskatchewan border Judith River strata are occasionally capped by outliers (principally the Cypress Hills) of Bearpaw and younger formations. In a north/northeast line linking the Milk River Ridge, Lethbridge and Brooks, the Judith River Formation becomes concealed in the east limb of the main Alberta Syncline. Along the U.S. border, older formations are exposed along the Milk River area between Ranges 6 and 16. Between these contacts, exposures are sporadically distributed as badlands along the Red Deer, Bow, Oldman and Milk Rivers and the network of coulees between Taber and Manyberries.

McLean (1971) thoroughly reviewed various definitions for the base and top of the Judith River Formation. Concerning the basal transition from the Pakowki Formation, the upper limit of a series of coarsening-upward, progradational cycles beneath the McKay coal zone seems to be the most logical one. The Judith River/Bearpaw contact is typically abrupt (Habib, 1981) and

has caused relatively little debate. Defined in the above manner, the Judith River Formation in the study area thins eastwards and north-eastwards from ca. 450m in the extreme southwest to ca. 280m beneath the Cypress Hills and ca. 325m in Township 23, Range 16, east of which oil and gas wells are spudded below the Bearpaw base.

The north-northeastward plunging Sweetgrass Arch is clearly the predominant structure in the region (Williams and Burk, 1966). According to Tovell (1958), it is a composite feature linking the neighbouring Kevin-Sunburst dome in Montana with the Bow Island Arch north of the point of confluence of the Bow and Oldman Rivers. Down-plunge, its axis crosses the Red Deer River immediately east of Dinosaur Provincial Park. Axial plunge decreases northward from 3.4 to 0.8m/km south and north of Township 12, respectively. Regional dips very from a maximum of 4m/km east of the Sweetgrass Arch, west along Township 12, to more than 16m/km where the main synclinal axis is nearby. Here, minor near-surface flexures were noted by Irish (see Section 10.1).

Active since the Paleozoic, the Sweetgrass Arch is a conspicuous feature on structure contour maps of the top of the Milk River Formation where it has the form of a mild anticlinorium (Fig. 7 in Meyboom, 1960). Its influence on Late Cretaceous sedimentation is uncertain partly because of the depth of erosion over its axial region. However, Wells (1957) concluded that movement continued into the early Tertiary, and in Dinosaur Provincial Park part of the bedrock joint distribution is apparently related to the stress field associated with the Arch (see Section 3.4). Outcrop data in the Park will be used to check Beland and Russell's (1978) suggestion that paleorivers across

the area had steepened gradients over the Arch. As McLean (1971) notes, the term Sweetgrass or Bow Island 'Arch' may be a misnomer in that it appears to have separated two more rapidly subsiding areas on its flanks - namely the Alberta and Williston Basins.

3.6 Energy Resources

3.6.1 Coal

The first coal production in Alberta was from the upper Judith River strata near Lethbridge in 1872 to supply customers in Montana, and later in Medicine Hat. Synthesising data from Campbell's (1964) catalogue of larger-scale registered mines in the Plains indicates that Judith River coal exploitation reached its peak in the early 1920's (Fig. 9): the average thickness of worked seams was about 1m thick. The last operating mine on Judith River coal was the Taber Ajax mine which closed in 1974.

Data from 41 samples ranging in depth from 51-250m acquired during the Alberta Research Council's 1976 regional drilling program has been synthesised by Nurkowski (1984). Judith River seams average 0.66% sulfur, 16.6% ash, equilibrium moisture 13.9% and 20,104-29,356 kg/kj in calorific value (moist, ash-free basis). These coals therefore range in rank from sub-bituminous C to high-volatile bituminous C.

Virtually all of the Formation's coal occurs in three zones, each separated by at least 100m of barren strata. In stratigraphic order, the common nomenclature applicable to the Western Plains (Holter and Chu, 1978) is McKay (immediately above the Pakowki/Judith River transition), Taber, and Lethbridge (immediately below the Judith River/Bearpaw contact) dominated by the Galt seam. In eastern areas, Holter and Chu noted that diachronism in the

Judith River base causes the Taber to become the lowest coal zone. Neither of the studies by Yurko (1976) or Holter and Chu (1978) had sufficient data bases to allow reserve estimates. However, such was possible by Campbell (1974) for the area enclosing the Cypress Hills. Figure 9a of the Energy Resources Conservation Board (1982) traces the outcrop and approximate 600m structure contour of the upper two coal zones across the southern Plains.

Sporadic development of coal zones appears to have resulted from a dense time-space distribution of paleochannel systems. Paludal environments therefore had a low probability of being either sustained for sufficiently long periods or being adequately remote from channel activity. The basal McKay seams developed in a delta-top situation (cf. Ryer, 1981) whereas the uppermost widespread Lethbridge Zone reflects the imminent submergence by the relatively rapid Bearpaw transgression. In between, the Taber zone is speculated to have been the result of a change in rate of regional tectonics/subsidence and/or hydrologic regime.

Current emphasis in prospective coal development is on strippable reserves for on-site conversion or nearby generation of electricity (Campbell and du Plessis, 1982). The Brooks/East Brooks' fields contain 79% of the surface Judith River resources, and are proposed by Campbell and du Plessis as a suitable site for a mated power/pyrolysis industry.

3.6.2 Hydrocarbons

This section briefly reviews published data on hydrocarbon reservoirs in Judith River strata as background to the potential economic significance of sedimentological research in the Park.

The Judith River Formation is generally the youngest hydrocarbon producing formation in Alberta. Shouldice (1979) recognized an eastward increase in porosity across the Plains limb of the Alberta syncline, and concluded that traps occur as 1) updip marine pinchouts into marine shale, 2) gentle structures involving widespread sands, and 3) fluvial paleochannel sands. The first two types predominate (cf. the Pembina field described by Iwuagwu and Lerbekmo (1981)) and characterize the basal part of the unit above the Pakowki Formation. Of relevance to work in the Park are the limited gas accumulations in paleochannel sandstones higher in the Formation, but Shouldice also detected a few east-west trending sandbodies of much greater extent.

4.0 SEDIMENTARY FACIES ANALYSIS

4.1 Previous Research

Figure 11 indicates the geographic location of major post-1960 contributions to a sedimentological understanding of the Belly/Judith River Formation across southern Alberta. However because of location or the specific stratigraphic interval of interest, little of this previous work bears directly on the upper part of the Formation exposed in Dinosaur Provincial Park. The regional stratigraphic investigation of McLean (1971), and the work of Dodson (1971) therefore remain prime reference articles. As pointed out by Walker and Haywick (1982; p. 151), "there is no summary article on the general depositional facies and paleocurrent trends of the Belly River Formation".

Studies in the Foothills belt, typically on dipping gorge exposures, have been generally concerned with the Wapiabi/Belly River transition zone. The regressive phase of the Wapiabi sea appears to have accumulated as upward-shoaling cycles of burrowed mudrocks below wave-base and storm-emplaced sands (Walker, 1982). Marsaglia and Klein (1983) in a global synthesis of occurrences of swaley and hummocky cross-stratification concluded that the southwest Alberta area was then affected by winter storm weather at 57°N paleolatitude. At Ghost Dam, Walker and Haywick (1982) recognized eleven fining-upward, fluvial paleochannel sequences in the basal 122m of the Belly River Formation. With some direct evidence of lateral accretion, these units average 1.9m thick (maximum 4.2m) and have vertical sequences from trough cross-bedding to ripple cross-lamination. Flow directions are clustered between northeast and southeast, and the rate of channel to overbank sediments

is approximately 3:1. Walker and Haywick were uncertain how this Ghost Dam sequence fits with respect to the overall scale of contemporaneous fluvial activity.

In the plains region, Ogunyomi and Hill's (1977) study in the Milk River area on the up-dip, correlative Pakowki-Foremost transition recognized a cyclic sequence of lagoonal and barrier-bar sediments. No fluvial sequences were found, so that their vector mean of 040° possibly represents the direction of longshore sand transport - a process which they envisaged. Their comparison of this transport direction with Dodson's (1971) 085° vector mean from channel-related cross-beds in Dinosaur Provincial Park therefore seems inappropriate. At Chin Coulee where a middle portion of the Judith River is exposed, Shawa and Lee (1975) deduced a southerly vector mean from freshwater cross-beds. The large volume of interdisciplinary work on the Strathmore corehole (Tp. 25, R. 25 W4), which penetrated the upper ca.20 m of the Judith River Formation, revealed an abrupt basal contact with the overlying Bearpaw Formation.

With respect to Dinosaur Park, the work of Dodson (1970, 71) on the local sequences and taphonomy of quarry sites remains a very useful summary account, although some facies properties are interpreted differently here (e.g. 'inclined heterolithic stratification' as the result of estuarine point bar accretion rather than deltaic progradation into standing water bodies).

Very recent sedimentological work includes Koster (1984, 1986a,b, 1987), Koster and Currie (in press), Visser (1986) and Wood (1986). Useful manuals for the identification of fossil plants/invertebrates and vertebrates are Stanton and Hatcher (1905) and Johnson and Storer (1974), respectively.

Bibliographic information on vertebrate fossils is provided by Danis (1980) and Russell (1976). Some palynological work has been done by Jarzen (1982) using matrix sediment from excavated turtle carapaces (see Section 5.5).

4.2 Objectives and Methodology

Although facies definition is the fundamental step in modern paleoenvironmental research after familiarization with the given outcrop, the scale of subdivision depends on objectives, time and abundance of apparent facies criteria. Given the need to systematically examine the huge expanse of exposure in the Park area, these factors required careful assessment in the initial planning stages of fieldwork. Good sections are ubiquitious, and opportunities for lateral tracing in many orientations with respect to local paleochannel direction(s) are abundant. In that patterns of facies variability were uncertain, a statistical approach to the spatial frequency of data acquisition was selected (McCammon, 1975).

Northings in the metric Mercator coordinate system (Fig. 3) were used as the traverse lines, commencing at the western limit of badlands (i.e. most proximal paleoenvironments). Lines of traverse were first marked in the field by a series of flag markers, using transparent copies of the 1:10,000 topographic maps on air photos of the same scale (Section 10.2). This navigational stage also provided the opportunity for preliminary reconnaissance. The second, major stage is to generate a stratigraphic profile of the traverse. Using the above-mentioned maps and air photos to determine location (to the nearest 10m) and elevation (to the nearest 2m), a Jacob's staff was used to measure the vertical sequence at frequent points along the traverse. Appropriate distances between such points were

determined on-site mainly on the basis of outcrop continuity and thickness variation of major units, but rarely exceeded 250m. Major emphasis was placed on the vertical and lateral extent of paleochannel bodies (Koster, 1983; Fig. 12) in terms of their sequence, contacts, facies, paleocurrent information and macrofaunal/floral contents: as well, major features of intervening overbank units were recorded. After preliminary plotting of this data, the traverse was walked for a third time to verify major elements.

Lengthy photomosaics of straight coulee walls (cf. Rahmani, 1982) around the south-eastern edge of the Park are now becoming a useful supplement to earlier traverse work.

4.3 Description

4.3.1 Introduction

Geomorphology of the badlands accentuates the fact that Judith River strata are readily divisible into 'coarse and fine members' (Fig. 13). As conventionally defined, coarse/fine member ratios vary from 0.4 to 2.9. However, the fact that the length of exposures typically exceeds their height stresses the point that the standard procedure of basing such ratios on a few vertical sections misrepresents true values for successions where channel bodies are multi-storey/lateral and not uniformly distributed in time and space across the basin. In such cases, the ratio of coarse-to-fine members is a complexly-distributed variable which is better determined by comparing the subtotals of cross-sectional area occupied by each member.

Dodson (1971) considered that paleochannel units comprise about 70% of sequences within the Park, and by synthesising earlier data found that all but one of the 84 then known dinosaur quarries were located in coarse members.

However, the rather common amalgamation of coarse members, particularly in the eastern part of the Park, was not recognized by Dodson.

4.3.2 Channel Sequences

Facies assemblages attributable to channel deposition can generally be assigned to one of two easily differentiated, end-member groups: - 1) Type I units dominated by 'inclined heterolithic statification', abbreviated IHS (Thomas et al., in press); and 2) Type II units of dominantly large-scale, trough 'cross-bedded sandstone', abbreviated CSS.

4.3.2.1 Type I units

A slight majority of the coarse members fall into this category. Their most prominent feature is lateral-accretion bedding (Fig. 14), conspicuously outlined by sloping sand-mud couplets or less commonly by ironstone horizons. The nature and degree of textural heterogeneity varies considerably. Relative abundance of traction-deposited layers varies from 15-90% (cf. Terwindt and Breusers, 1972), although prior to compaction of the cohesive interbeds these limits would have been somewhat lower.

Individual couplets (usually on a scale of a few decimetres) typically have an erosional base and fine upward. This takes the form of an increasing frequency of mudstone laminae, although sandstone and mudstone units defining a couplet are well segregated. The sandstone units are very fine to fine grained and rarely concretionary. Wherever internal structure is discernible, they show ripple cross-lamination often with thin mud laminae draping lower foresets. Scattered imbricate small intraclasts are sometimes present. Most horizontal partings are smothered with carbonized plant or stem debris that rarely display preferred orientation. The intervening mudstone units are

bentonitic, rich in well-preserved palynomorphs, olive or brownish grey and invariably contain carbonized flecks of plant matter. In finer detail, and with the aid of polished slabs, these units may contain extremely thin silt laminae.

Couplets contain a small variety of trace fossils, including Planolites and Skolithos although not all have yet been identified. Rooting, desiccation or other signs of pedogenesis have not been observed. Iron-cemented silty sandstones upto 15cm thick, on the other hand, commonly contain vertical rootlet markings which are occasionally made obvious by small-scale differential weathering around stem positions.

Inclined heterolithic stratification occupies the full depth of Type I units. However, the basal part of thicker examples may be sand-dominated, (Flach and Mossop, 1985), in which case there is an up-slope intercalation to sand-mud couplets (Fig. 15). In the latter case, defined as Type A or B depending on thickness of the basal sand layer, partly concretionary cosets of trough cross-beds up to 70cm thick and up to 1-2m wide are common. Vector means of such structures deviate from the dip direction of the host IHS by between 70^{o} and 140^{o}, but the average is 94^{o}. Isolated vertebrate bone fragments and pebble-sized mudstone intraclasts are invariably aligned perpendicular to adjacent cross-bed azimuths.

Irrespective of the downward extent of lateral-accretion bedding, accretion surfaces are planar or mildly concave-upward. However, the inclination of sand-mud couplets is occasionally interrupted by steeper reactivation surfaces (Fig. 16) or miniature growth faults. Basal surfaces are sharp and planar over observed distances of several hundred metres.

Gradational upper boundaries are ubiquitous, and they are commonly underlain by ball-and-pillow structures (Fig. 17).

In the 121 laterally-accreted units measured thus far, data on thickness and inclination are log-normally distributed. The average sequence is 3.8m thick and dips almost at 7°, but units approaching 20m have been sighted off traverses (Fig. 18). Vectors of lateral-accretion bedding are distributed with modes between 330°-060° and 120°-240° (Fig. 19A), and there is no obvious tendence towards a different spatial configuration for the thicker units. The vector mean of 63 contained cross-beds is 084° with a magnitude of 51%. Although the lateral extent of accretion bedding commonly exceeds 200-300m, several localities at which the structure begins and ultimately pinches out are known.

4.3.2.2 Type II units

Units of this category (Fig. 20) account for about 40% of the coarse members. The absence of lateral-accretion bedding, the minimal presence of mud-sized sediment and abundant, large-scale cross-bedding render this type of sequence distinct from the preceding facies assemblage. An overall, upward-fining trend from medium to fine or very fine-grained sandstone is discernible in about a third of the examples, but a consistent vertical organization in scale and/or type appears to be lacking (Fig. 21). Their cleaner, more coarse-grained texture typically contributes to steep, rilled scarp exposures.

Sequence thicknesses are log-normally distributed, and range from 1.4 to 12.6m with mean 5.9m. Bases are erosional with varying concentrations of coarse detritus, and the thicker members occasionally exhibit local erosional

relief up to 1.4m with progradational infills (Fig. 22). Concentrations of disarticulated skeletal parts (i.e. bonebeds) or articulated skeletons commonly overlie these erosional contacts. In fact of the 84 dinosaur quarries studied by Dodson (1971), 81% had been excavated from these units with all stages of skeletal decomposition noted. Concentrations of teeth, small bone and carapace fragments (i.e. microsites) are commonly weathered out in rill networks across these units.

In terms of overall horizontal geometry, these units have linear ribbon form, with a predominant east-south-eastward direction based on vector means of contained cross-beds. Lateral joining of these sandbodies has not been observed. In a few instances, both lateral pinchouts have been detected with transverse widths of approximately 230m. Isopachs of the sand body inside these margins reach maximum values rapidly, thereby causing a high probability of encountering a uniform unit thickness in traverses. Within outcrop limits, lengths of units with above average thickness have been found to exceed 1.3km, but considerably greater dimensions are anticipated.

The clean, well-sorted texture of these sandstone units means that the geometry and vectorial properties of current structures are usually only clearly discernible within calcareous or ferruginous concretions. Very reliable measurements can be made where differentially-weathered concretions are exposed on pediment surfaces. Current structures, in order of abundance, are cosets of large trough cross-beds, intervals of ripple or rarely climbing-ripple cross-lamination, single extensive sets of planar tabular cross-bedding, and intervals of horizontal lamination. Set boundaries of cross-beds are often lined with stringers of pebble-sized mudstone

intraclasts, occasionally mixed with pebble to small cobble-sized extrabasinal, mostly quartzite clasts. Foreset laminae occasionally contian rhythmic mud drapes (Fig. 23).

The abundant sets of trough cross-beds, which have an ESE vector mean (Fig. 19B), have measurable transverse widths upto 22m and heights of 1.5m. However, both parameters are log-normally distributed due to reactivation which commonly removed their upper parts causing the ratio of width/height to vary from 1:1 to 40:1 (Fig. 24). In a few localities, upper set boundaries have trace fossils preserved: these are the unornamented tubes of crustaceans (S.G. Pemberton, personal communication, 1983). Linear progradation of troughs up to 18m has been noted on pediment exposures, with some foresets showing evidence of regular, episodic deposition of very thin mud drapes. The direction of trough axes within cosets rarely deviates more than 35^{o}.

Directions of foreset dips in wedge/planar-shaped sets and axes of trough-shaped sets generate virtually identical east-southeast vector means, although the latter group has higher vector magnitude. Weighting of cross-bed data according to set thickness only slightly improves vector magnitude, probably because of the frequency with which upper set boundaries were reactivated.

4.3.2.3 Composite units

Type I IHS and Type II CSS sequences, as described in the previous section, are the primary architectural elements in a spectrum of paleochannel sequence types. Representing a trend of increasing energy and apparently diminishing sinuosity, the spectrum consists of five main types as follows (Fig. 25):-

Type I: Composed entirely of IHS.

Type A: IHS above CSS, with the conformable contact between point bar and coarser thalweg facies either intercalated or relatively abrupt at (1-3m above the base. Locally, single cosets of trough cross-beds show a landward direction of paleoflow.

Type B: 'Streaky' occurrence of IHS at mid-upper levels in a CSS-dominated sequence.

Type C: Inclined intervals of densely-packed intraclastic breccia composed of reworked IHS lithology and fragments of siderite concretions, alternating with CSS.

Type II: Composed entirely of CSS.

The above list covers observations from vertical stratigraphic sections. Complete channel sequences, when viewed in a north-south transverse orientation, either show simple or composite form. The former are infilled by one end-member vertical sequence type. In Type I cases, the IHS starts at a cut bank and ends at an abandoned, 35-50m wide cross-section of the channel bend. In Type II cases, the CSS is contained within a broad bowl-shaped cross-section for which the total width/thickness ratio tends to increase down paleoslope from ca. 40 to 70. In composite channel fills, common transitions involve I → B , I → C, B → II and C → II, indicating that the lateral accretion process was prone to various reduced forms of identity along dip.

Jackson (1976) recognized a distinct proximal to distal differentation of facies sequences around point bars, and that preservation of these depends on the geometry (expansional, rotational or translational) of meander growth. Significant considerations relating to the nature and distribution of facies

within point bar sequences are as follows. Firstly, temporal changes accompanying meander growth are 1) decreasing thalweg gradient, 2) an accentuated spiral component to bend flows, and 3) increasing cross-section asymmetry and concomitant change in hydraulic geometry. Secondly, important distinctions with respect to the spatial distribution of point bar facies are 1) outlining of the lateral accretion process by sporadic, discontinuous mud drapes versus cyclicly regular mud-sand couplets, 2) concurrent versus sequential facies changes, and 3) sequential changes produced by juxtaposition of proximal against distal sub-environments versus an externally caused modification in channel form and hydrologic regime over time.

4.3.2.4 Amalgamation

This term refers to the vertical stacking of at least two superimposed channel sequences (Fig. 26). Amalgamation arises when there is an inadequate rate of subsidence or alluviation and/or a relatively fast rate with which channels re-occupy a given part of the alluvial plain.

The surfaces of channel amalgamation are laterally extensive. They also represent significant time gaps and a missing part of the sequence which may have included both the top of the earlier channel-fill and an overbank 'fine member' accreted vertically above it. Lateral tracing of units within a amalgamated sequence is the only way of determining what may have been initially present, and this can be done in many parts of the badlands.

In the hierarchy of scour surfaces within alluvial sequences, amalgamation represents the largest scale and involves the greatest period of time. Near the other end of this spectrum are the common, local reactivation surfaces within a channel-fill episode which merely reflect minor bed scour before further accumulation.

Superposition of up to four channel-fill episodes has been discovered in the Park outcrops, but features of the dividing amalgamation surfaces vary according to the type of facies assemblage present within each episode. Amalgamation is most conspicuous in stacked Type I sequences where successive units of lateral accretion commonly have opposing dip directions. Accretion in the younger set is conformable to a lower boundary which truncates the older set. This feature indicates the stacking of different generations of point bar sediment. Amalgamation between stacked Type II sequences is more subtle because of their mud-free texture and apparent vertical aggradation. A coarse-member thickness greater than about 8m leads one to anticipate that internal amalgamation exists, but ultimately a laterally extensive lag surface(s) must be located. Such lags consist of a mixture of bone fragments, logs/twigs, intraclasts, reworked ironstone concretions whole or fragmented, and the occasional extrabasinal clast. In other places, an indurated clast-supported conglomerate of pebble-sized intraclasts or merely an abrupt change to coarser sand signifies the superposition of channel-fill episodes.

The above-mentioned categories of lag constituents indicate that a variety of processes were associated with the development of an amalgamation surface. However, all have in common the fact that they were concentrated during and after removal of the overlying coarse and/or fine member. The size of many abraded and aligned bone grafments, often in excess of 5kg (now heavier due to mineral-filled pores from diagenesis), indicates shear stresses far greater than that required to entrain the enclosing sand. Amalgamation was therefore associated with a high-energy events on the alluvial plain.

The probable processes of accumulation for each main category of lag constituent were as follows:

- Skeletal debris because of its abraded and broken state, was concentrated by filtering from overlying units, mostly Type II, or by fresh influxes from scattered locations upstream.
- Ellipsoidal intraclasts of iron-hardened mudstone, often armoured with sand grains, were also filtered from overlying Type II units where they commonly occur.
- Angular, soft intraclasts of pale mudstone were freshly produced during removal of an inter-channel unit formerly present between the amalgamated coarse members.
- Ironstone concretions of argillaceous texture were also derived from units of inter-channel sediment formerly present between amalgamated coarse members. Siderite concretions commonly form early in the near-surface levels of poorly-drained, carbon-rich mud, as observed by the first author in the upper delta backswamp deposits of the Mississippi. Their occurrence here points to the fact that the time elapsed between re-occupation of a given area by channel activity was sufficiently long to have allowed early diagenesis in inter-channel sediments. However, a newly avulsed channel evidently encountered little resistance in removing these deposits.

4.3.3 Inter-channel Sequences

These envelop, in a three-dimensional sense, the coarse-member paleochannel sequences. Local thickening to a maximum of 18m has been noted (Fig. 27), but intervals of 1-4m are typical. Elsewhere, coarse-member amalgamation led to the removal of these overbank units. Sequences external to paleochannels consist mostly of olive grey, commonly rooted mudstone and

are often capped by horizons of large ironstone concretions. Mudstone intervals are occasionally interrupted by rippled muddy sands representing splay events, thin Unio-bearing iron-cemented sandstones (see Section 5.4), rare layers of volcanic ash, and carbonaceous shales and thin coal seams in levels equivalent to the Lethbridge Coal Zone (see Sections 2.3.2 and 3.6.1). This section deals only with the mudstone intervals because these predominated during sedimentation in inter-channel areas. Associated facies represent relatively exceptional events.

Inter-channel mudstones are commonly deeply weathered. This arises from a high percentage of montmorillonite, up to 65% in Belly River Formation mudstones of the Foothills according to work by Lerbekmo (1963), which readily absorbs precipitation causing disruption of near-surface fabrics. When dry, surfaces become rough and crumbly (so-called 'popcorn' texture).

Firstly, palynological analysis show a well-preserved continental assemblage (representing conifers, cycads, ferns, lycopods, hornworts, mosses and angiosperms), identical in composition to that recorded by Tschudy (1973) from the Judith River Formation of Montana. However, very occasional damaged specimens of acritarchs (Pterospermella sp.) or dinoflagellates (Bacchidinium ploypes, Cleistosphaeridium sp.) were also spotted. Petrified logs of Taxodioylon gypsaceum (Dodson, 1971) with diameters from 30-95cm occur sporadically, but very rarely in growth position. While articulated vertebrate skeletons are virtually absent, isolated bones do occasionally occur.

Using the GSA's rock-colour chart, colour which is known to be a reasonably reliable indicator of chemical composition (Blatt et al., 1980:

Fig. 28) is variable within three trends (Fig. 29). However, half of the samples are olive grey which is normally associated with poorly-drained, carbon-rich environments. Percent carbon varies by four orders of magnitude up to 5%, and specimens with a high proportion of macroscopic plant fragments are darker overall with a high volume percentage of disseminated organic matter.

Mudstone intervals appear to be massively bedded, although trenched intervals generally reveal transitional changes in texture and/or colour. Rootlet traces are common, but most often associated with light to olive grey intervals that are densely fractured. Certainly, an investigation of other more subtle signs of pedogenesis would be a rewarding research topic (cf. Retallack, 1983). Present-day weathering is responsible for the surficial concentrations of gypsum crystals which commonly lie strewn over sulfur-rich intervals.

As with apparently massive freshwater clay sequences in Mississippi (Coleman, 1966), X-ray radiographs on these analogous mudstone sequences is revealing inhomogeneties in the form of delicate lamination and possible gas escape structures (Hamblin, 1962). Other X-rayed samples show a mottled, completely disrupted texture which may have been due to the trampling action by vertebrates (Laporte and Behrensmeyer, 1980).

The early-formed horizons of siderite concretions (Postma, 1982), which preferentially occur in the uppermost levels of mudstone intervals below the base of a paleochannel unit, preserve uncompacted sedimentary structures (McKee and Goldberg, 1969) and floral/wood debris (cf. Gauthier, 1982).

4.4 Interpretation

This concluding section interprets the facies assemblages, particularly those of paleochannels, to build a local scenario for sedimentation on the distal, low-gradient reaches of a foreland coastal plain.

4.4.1 Basin Setting

In terms of the overall regional setting (see Section 3.0), paleodrainage flowed east-southeastwards to a nearby encroaching shoreline of the Western Interior Seaway. Water discharge and sediment loads of these fluvial systems were ultimately derived from orographic rainfall and weathering within the newley-uplifted front ranges of the Cordillera, 400-500km to the west. However, a significant amount of reworking of young alluvium within the basin occurred rather frequently. The eastern end of the Park overlies the axial region of the Sweetgrass Arch (Section 3.5), which appears to have been active during the Campanian, thus causing a reduced rate of subsidence for overlying sequences.

The prevailing climate was warm and moist. It supported a dense flora on the coastal plain which was traversed by a changing network of rivers and overbank areas. In turn, these supported a varied fauna of aquatic reptiles, amphibians, fish and trace-making invertebrates. Overbank vegetation supported a large population of herbivorous reptiles which, further up in the food chain, maintained a less abundant group of carnivores.

Perhaps no other geological site gives, by virtue of its high fossil record, such a vivid impression of a diverse, now extinct assemblage of terrestrial life forms.

4.4.2 Inter-channel Sequences

The predominantly fine-grained texture of these sequences without obvious paleosols indicates that mud-laden floodwaters from adjacent channels frequently spilled over into inter-channel areas where fallout of the suspended load occurred. Relatively few of these overbank events were sufficiently competent to introduce uncohesive traction sediments, judging from the rarity of sandy splay units.

How long each pulse of floodwater lingered in inter-channel areas is difficult to determine. Cyclic changes in groundwater conditions and degree of oxygenation are reflected by the rhythmic colour trends and concretionary horizons (see Section 4.4.3) through thick sequences. The inter-channel flora was undoubtedly hydrophytic but able to withstand periodic draining of surface water. Rootlet traces are common, but reports of *in situ* trees and larger root systems are exceedingly rare. Consumption of flora by herbivorous dinosaurs occurred on a major scale (Beland and Russell, 1978), and therefore trampling of these soft wet sediments, given their slow rate of accumulation, was probably a ubiquitous process.

4.4.3 Type I Paleochannels

The IHS structure points to regularly fluctuating, low-energy, mixed-load flow around bars in laterally-migrating, single-channel systems. Point bar growth was incremental: brief periods of sand deposition from lower-flow regime traction currents alternated with somewhat longer periods of fall-out of suspended mud. The structures in sand-mud couplets and overall style of inclined heterolithic stratification (IHS) resemble those of meandering estuaries (Koster, 1986a, b; Thomas et al., in press). Complete repetitious

coverage of point bar surfaces by unrooted and undesiccated sand-mud couplets with several internal orders of cyclicity, fine-grained sediment drapes is not resolvable with fluvial velocity-stage relationships.

Thalweg gradients were very low, conventional paleohydrologic methodology suggesting that these were in the range of 0.0003 to 0.005. Average depth and width of flow around point bars, which tended to grow with expansional geometry, were upto twice that of the modern Red Deer River through the Park (although distinct differences in meander geometry should be noted in this comparison). The lateral persistence of IHS over several hundred metres, both parallel and perpendicular to the vector of accretion indicates that point bar environments were stable, equilibrium features on an aggrading plain very close to base level (i.e. the Western Interior Seaway). The distribution of Judith River IHS vectors indicates that these paleochannels migrated primarily by sideways expansion (see Section 4.3.2.3).

4.4.4. Type II Paleochannels

Type II sequences clearly reflect a much higher energy level in which the main fill process was the vertical aggradation as a sheet of large sinuous-crested, sandy bedforms. A high average flow velocity and/or scour-and-fill processes prevented widespread preservation of suspended-load sediments. Flow directions varied little, and coupled with the other diagnostic features, point to relatively straight, non-migratory systems. Unequivocal evidence for subaerial exposure of any bar-complexes is lacking.

The thickness of each paleochannel sequence compared to its largest contained cross-bed set is considered to be an approximate indicator of the number of aggradational cycles needed to complete channel fill: such ratios

range from 4 to 7. In sequences containing transported large dinosaur carcasses, flow depth must have exceeded the animal's girth (up to 1.5m). Type II channels appear to have shallowed progressively after the initial erosive, avulsion event (Fig. 21). As such, there is no apparent similarity between the vertical sequences of these channels and the 'type' examples for sandy braided systems synthesised by Miall (1977).

Fluctuating discharge causing cycles of scour-and-fill is indicated by 1) occasional deposition of cohesive sediment and its subsequent local redistribution while still wet, as mudstone intraclasts (Smith, 1972), 2) the extensive angular truncation of upper boundaries in large cross-beds sets, and 3) the lack of preservation of intact vertical sequences. Actual competence levels of paleoflows were considerably higher than those needed to transport the bedload of predominantly fine sand and to generate large bedforms. This is indicated by traction transport of rounded mudstone intraclasts and quartzite cobbles (ca.700g) and isolated limb bones commonly up to 1m long (ca. 22kg.), both with current-normal alignment.

4.4.5 Paleonenvironmental Scenario

This section builds on the points raised in Sections 3 and 4 as they relate to observations of paleochannel sequences in the study area.

Four features of the coastal plain succession are considered critical to interpretation - namely, origin of IHS, variability in paleochannel processes (Fig. 30), vertebrate taphonomy (see section 5) and the nature of 'fine members'. Each is briefly discussed below in the context of an estuarine setting.

As used here, an estuary refers to the near-coastal, widening reach of a

river down which alluvial processes are increasingly modified by tidal circulation and saltwater incursion (cf. Jouanneau and Latouche, 1981; Dorjes and Howard, 1975). Commonly, a transitional series of zones exists between strictly fluvial conditions upstream of the fall line and the open sea (Figs. 31-33). Zonal boundaries oscillate on timescales relating to the lunar tidal cycle, seasonal river regime and periodic onshore storm surges, whereas the entire estuarine system will shift in response to transgression or regression (Fig. 34).

IHS is viewed here as a distinctive style of lateral accretion in tidally-influenced point bars. Sand-mud couplets relate to rhythmic additions of traction-deposited sand and fallout of suspended fines. Complete coverage of the point bar slope by undesiccated and unrooted mud drapes shows that bankfull velocity was minimal and subaerial exposure was briefly, if ever, attained. Along the upper sinuous reaches of modern estuaries, sluggish river flow alternates with slackwater, the latter induced both by rising tide and diminished slope of the water-surface. When river discharge is high there is less opportunity for backwater and mud deposition (Fig. 35). An estuarine setting also provides a coherent framework for the variability in paleochannel types (Fig. 25), with Type I as the upstream end-member in the 'tidally-influenced river'zone. Type II sequences are considered to have formed within the lower estuary under fluctuating, relatively high-energy flow (cf. Lithofacies I of Terwindt, 1971). It is envisaged that Types A and B formed at intermediate locations in the 'stratified estuary' zone. Type C represents a major local change in channel process and form, whereby IHS-forming point bars were suddenly rendered unstable by extreme flow conditions.

In the western, more proximal end of the Park, paleochannels tend to be enclosed by inter-channel sequences; further eastwards, amalgamation with older channel sequences is more prevalent. Furthermore, Type II channels are more common at high stratigraphic levels than Type I, as would be expected with this model. Neither channel type resembles that described by Walker and Haywick (1982) from the basal levels of the same clastic wedge at Ghost Dam (Section 4.1). This proximal location of paleodrainage within the basin was on a steeper slope and presumably more remote from the prevailing base level.

Clearly, avulsion and amalgamation of paleochannels both played a major role in concentrating vertebrate remains (see Sections 5.2 and 5.3; Fig. 30). Whereas buried carcasses indicate a short single episode of movement from a nearby site of death, disarticulated bone fragments commonly show signs of prolonged wear. Given that fluvial transport of fossil material is effectively halted within the estuarine zone (Frey et al. 1975), only a small portion of the preserved population may have inhabited the immediately surrounding inter-channel environments.

Because modern estuaries are flanked by various floral communities (Fig. 32), the paleochannels probably inherited a mixed sample of estuarine flora (cf. Jarzen, 1982). The low frequency of splay events in overbank areas is a consequence of the low-energy nature of bankfull flow in tidally-influenced channels.

This hypothesis on the variable form and process of near-coastal Campanian channel systems is an example of the approach advocated by Bridge and Diemer (1983; p. 599) who stated that:

"Confident and comprehensive interpretations of ancient river-channel

deposits can only come from thorough description of their three-dimensional lithofacies characteristics, and a full quantitative understanding of the physical processes of sedimentation acting in past and present river channels."

On a similar note, Miall (1983; p. 284) has concluded:

"There is a great need for detailed studies of fluvial architecture in three dimensions, in order to explore fully the range of sediment body-shape variations outlined by Friend (1983). Unfortunately, well-exposed, structurally undeformed sections in which such research can be performed are not that common ..... Because vertical profiles are so widely used by subsurface geologists it would be useful to continue the effort to relate such profiles to geomorphic process ..... Our efforts to classify and model fluvial sediments on a basin scale are hampered by a lack of thoroughly studed, well-documented case histories. Therefore there is much room for basic, descriptive research. However, the research should be as broadly based as possible ..... it is only by adopting a multidisciplinary research method that we can hope to understand fully how a particular basin was filled."

The study of facies and paleoenvironments in Dinosaur Provincial Park is offered as a contribution with the above philosophy in mind.

5.0 PALEONTOLOGY

5.1 The Vertebrate Record - An Overview

Dinosaur Provincial Park has long been renowned as one of the world's major sources of dinosaur specimens (Table 2). More than three hundred significant finds have been made, and dinosaurs from this region are on display in more than thirty institutions throughout the world. The majority of these specimens were collected between 1912 and 1925, the period of the so-called 'Great Canadian Dinosaur Rush', after which collecting activities were curtailed. Since 1978, however, there has been steady increase in collecting and research in Dinosaur Provincial Park, primarily by the Tyrrell Museum of Palaeontology, with assistance from scientists from the National Museum of Natural Sciences, University of Pennsylvania, University of Calgary and the Alberta Research Council. Correlation with other Judithian sites in Alberta and Montana is being refined as detailed work on the depositional environments, fauna and flora increases our understanding of the ancient ecosystem (Dodson, 1983).

In addition to scientists, a large crew of Tyrrell Museum technicians and volunteers work in Dinosaur Park every summer. They are divided into smaller teams who either prospect and record data on new fossil resources, excavate significant specimens, or continue a long-term excavation program at the Centrosaurus bonebed, #143 (Currie, 1982b; see Section 5.2).

These surveying teams retain the type of field interests of pinoneer paleontologists during the 'Great Canadian Dinosaur Rush' in terms of museum quality articulated specimens. Indeed, over the past five years superb specimens of Albertosaurus, Centrosaurus, Kritosaurus, Gryposaurus, Chasmosaurus, Corythosaurus, Lambeosaurus and Troodon (Currie, in press) have

been collected. But current Tyrrell Museum practice is broader, with the following four types of dinosaurs resources now being researched: 1) 'quarries' (removed articulated specimens or rare smaller remains), 2) 'uncollected articulated dinosaurs' (so-called UAD's - good prospects discovered, but not yet quarried), 3) 'bonebeds' (bedding-plane concentrations of commonly abraded, fragmented and disarticulated remains), and 4) 'microsites' (surface concentrations of fine-sized disarticulated remains). The main purpose of all collections data is to establish population counts for paleoecological and taphonomic interpretations.

5.2 Integrated Approach to Vertebrate Taphonomy

Taphonomy concerns all aspects of the entry of animal remains from the biosphere into the fossil record (Efremov, 1940; Koster, 1987). Taphonomic studies reach their optimum success when both paleontological and facies-related aspects of fossil sites are jointly considered. Mortality, and then carcass transport-decomposition-disarticulation-burial are a complex time series of interwoven biological and sedimentological processes. The current stage of sedimentological research in the Park enables the exciting merger of these two data sets to begin. Below is a brief synthesis of current taphonomic knowledge as it relates to Judith River sedimentation in the Park area.

1) The abundance, diversity and commonly articulated nature of vertebrate fossils are the vestige of a large, mixed herbivore-carnivore population having been ecologically well-adapted to paleonvironmental conditions in the same area. Habitats included both vegetated interchannel lowlands and water bodies (Dodson, 1971).

2) As a general principle, the degree of carcass decomposition and skeletal disarticulation relates strongly to the time elapsed between mortality and burial (Dodson, 1971). However, burial in channel sediments is potentially a complex, multi-stage process involving initial stranding, surficial reworking, burial and re-exposure by younger channel-fill episodes through lateral migration or vertical amalgamation (Koster, 1987).

3) Most of the individual vertebrates which became fossils, irrespective of the degree of disarticulation, died in river water (Dodson, 1971; Beland and Russell, 1978).

4) All preservation modes of vertebrates show an overwhelming association with the basal/lower levels of sand-dominated channel-fill sequences (Dodson, 1971). Mud-draped lateral accretion bedding, in contrast, rarely hosts fossils.

5) Disarticulated skeletal parts commonly have hydraulic equivalent sizes greatly in excess of the enclosing sediment texture indication that energy levels of bone movement were considerably higher than the competence required for bedload transport of the associated fine sand and mud intraclasts.

6) Census data of multigeneric bonebeds is statistically similar to that of quarried articulated specimens.

This project is presently considering two facets of dinosaurian taphonomy which will help elucidate the time elapsed and processes between death and ultimate burial. The first concerns the association between the location and cause of mortality (Fig. 36A). In terms of depositional setting, 'location'

includes inter-channel areas, either dry or under standing water, and channel water. 'Cause' can be categorized as scattered, isolate occurences in the case of old age or predation, or possibly simultaneous group occurrences in the case of drowning or disease. Secondly, processes of skeletal exposure and disarticulation are being linked with the biological and sedimentological agents of carcass destruction (Fig. 36B).

Field evidence supports the following rather clear association between facies and modes of vertebrate preservation.

MODE A: Isolated, articulated remains (i.e. Quarry Sites, excluding those of single bones of special interest, plus Uncollected Articulated Dinosaurs) -

These show an overwhelming association with the basal/lower levels of non-amalgamated, Type II paleochannel fills. Here the main facies is large-scale cross-bedding with set boundaries and lower foreset slopes lined with intraclastic gravel and comminuted floral debris. Skin impressions are sedimentologically significant in indicating incomplete decomposition of the stranded carcass before quick burial. The preferred association with the lower level of channel fill sequences implies that mortality and transport were in some way connected with the degrational episode responsible for the new channel.

MODE B: Thin, aerial concentrations of disarticulated, commonly abraded and broken remains (i.e. Bonebeds) -

B1: Mostly coarse herbivore remains

B1a: Multigeneric

These form part of channel-base lags, some preferentially cemented, composed of mudstone intraclasts, rare extrabasinal pebbles, small cobbles and reworked concretions. The richest bonebeds occur at the contact within amalgamated channel-fill sequences, which implies that intermixed bone and clastic material was filtered out from eroded intervals within the amalgamated sequence, combined with some horizontal sorting. The hydraulic-equivalent sizes of the elements with bonebeds indicate energy levels considerably higher than the competence required for bedload transport of the overlying fine sand. The corollary of this statement is that these paleochannels appear to have been under-supplied in coarse detritus which the system was actually competent to transport.

B1b: Mainly monogeneric

Exemplified by the Centrosaurus (Currie, 1982; Currie and Dodson, 1984) and Styracosaurus (Visser, 1986) bonebeds, this category is associated with the point bars of Type I paleochannel sequences. Lateral migration is outlined by inclined mud drapes and thin iron-cemented rippled, silty sandstones. The restricted faunal assemblage and point bar setting strongly implies that mass mortality occurred due to drowning a short distance upstream during high discharge. Increasing diversity in the faunal assemblage presumably correlates with a longer period of flotation before stranding, and thus greater dispersion downstream.

B2: Well-sorted, fine sized concentrates of mixed vertebrate remains (i.e. microsites).

The size of skeletal carapace fragments, scales, teeth etc. generally have hydraulically equivalent diameters in the granule to small pebble range. Because slopes need close inspection to spot this category, the details of their apparent preferred association within Type II paleochannel facies and only now being established (See Section 5.3).

MODE C: Isolated, abraded, commonly broken single bones -

Distinction in the field between inferior bonebeds versus 'isolated' bone is rather subjective, since the latter also tend to be located at the base of, or within, Type II channel-fill sequences. Disarticulation of the parent skeleton long proceeded the deposition and burial of its single bone derivatives. Rolling on the bed often over large dune bedforms caused considerable abrasion of the bone material. Long bone is typically aligned transverse to the direction of subjacent paleocurrent indicators.

The much publicized Centrosaurus bonebed at 678 m. a.s.l. and 1.5 km east of the Bus Tour Road, was discovered by Park officials in 1977, and systematic grid excavations by Tyrrell Museum personnel began two years later. Excavations are still proceeding. Covering at least 1,500m^2 and spanning up to 1.5m in the upward fining, carbonaceous part of a 7m thick laterally-accreted paleochannel sequence with mud drapes and ironstones, the spatial density of bone locally reaches 60 elements. Most bone is horizontal, and its skewed size distribution averages 17.3cm. Between 85-95% of the identifiable material is ceratopsian, an diagnostic skull bone belong

to the genus Centrosaurus - hence the bonebed's name. By contrast, in the rest of the Park, ceratopsians comprise less than 25% of the dinosaur assemblage. Based on an early sample of 525 elements (as of the 1981 field season), the composition of the remaining assemblage is 5% carnivorous dinosaur, 3.5% hadrosaur, 1.5% champsosaur, 0.5% ankylosaur, 0.5% turtle, 0.5% Myledaphus and 2.5% mammals, lizards, and other fish. Long bone elements at lower elevations are commonly aligned transverse to flow, and some vertebrae are even imbricated. Anatomically, the dinosaurian component of the bonebed comprises about 50% ribs, 20% vertebrae, 15% skull parts, 10% limbs and small numbers of foot and girdle fragments.

To summarize, the main features of this 'monogeneric bonebed' are the predominance of easily transportable elements, the fact that abrasion mainly affected the smaller size classes and a count of at least 50 juvenile-to-mature individuals. These points appear to indicate that the bonebed originated as a herd undergoing mass mortality by drowning, subsequent scavenging and trampling by therapods, then minor wasting after skeletal disarticulation. After six summers of excavations, only about 20% of the Centrosaurus bonebed has been excavated. Present estimates suggest that the total number of individuals contained in the entire bonebed may exceed three to four hundred. Ontogenetic development of Centrosaurus is now under study.

5.3 Vertebrate Microsites

5.3.1 Introduction

Upper Cretaceous microvertebrate sites comprising concentrated assemblages of disarticulated skeletal elements from a variety of small to large vertebrates are important sources of palaeoecological data (Estes, 1964;

Sahni, 1972). Microvertebrate sites are particularly abundant in the exposures of the Judith River Formation in Dinosaur Provincial Park. At present, over 50 sites are known. A combined palaeontological and sedimentological study of some of these sites is now underway in an attempt to assess their palaeoecological significance.

Dodson (1970, 1971) noted that microvertebrate sites characteristically occur in clay pebble conglomerates at the base of sandstones. He interpreted these as hydraulic accumulations of physico-chemical resistant parts of decomposed skeletons.

P.J. Currie began recording microvertebrate sites as part of a systematic inventory of the palaeontological resources of the park in 1979. In that year, 21 microsites were recorded. He found that the remains of individuals of greatly variable body size were preserved in microsites, and that microsites are sometimes part of bonebeds in which large bones were preserved. This supported the earlier conclusions of Dodson (1971) that microvertebrate localities represent hydraulic accumulations of the most resistant component of the skeleton.

Later sedimentological studies have reinforced Dodson's (1971) interpretations. Koster (1984) pointed out that, in general, microvertebrate elements have equivalent hydraulic diameters to granules and small pebbles, and suggested an association between microvertebrate elements with vertically aggrading river deposits. In a detailed sedimentological study of a small area within Dinosaur Provincial Park, Wood (1985) also concluded that microvertebrate assemblages are associated with trough cross-bedded sandstones of channel deposits. He followed Dodson in asserting that these are hydraulic

importance of microvertebrate localities for palaeoecological studies was established and considerable progress was made towards the definition of the Judithian dinosaur communities.

In 1985, it was decided to continue Dodson's survey through the use of underwater screenwashing techniques. The purpose of this study was to further our understanding of freshwater aquatic communities through an identification of patterns of co-occurrence of aquatic animals, and to synthesize this information with sedimentological data to identify any correlation in patterns of faunal composition with stratigraphic or environmental factors. This part of the study has had three principal results: 1) our understanding of the diversity of Judithian fish has been increased; 2) palaeoecologically significant associatons of animals have been identified and, in some cases, associated with particular environments of deposition; and 3) stratigraphic patterns in the distribution and relative abundance of animals have been identified.

5.3.2 Stratigraphic Context

The relative stratigraphic positions of the different microvertebrate localities were determined by utilizing the base of the Lethbridge Coal Zone as a datum. At thirty-four sites throughout Dinosaur Park and adjacent areas, the elevation of the base of the Zone, its thickness and number of beds were recorded. These data were then used to construct a series of structural contour overlays - compatible with the topographic maps of this region - that could be used to assess the relative stratigraphic positions of all microsite localities. In Dinosaur Park, the Lethbridge Coal Zone varies in thickness from 2.25m to 23.3m. On average, it is 8m thick with a standard deviation of 5.22m. Using one standard deviation as a measure of error, then the relative

stratigraphic positions of all microvertebrate localities with known elevations can be calculated +/-5.22m. While this may appear of little help between closely spaced localities where simple reference to elevations may be more accurate, it offers a means of correlating widely distributed localities within the Park and between the Park and exposures elsewhere on the prairie. Figure 37 shows the relative stratigraphic positions of the microvertebrate localities described in this field guide with reference to the base of an 8 meter thick exposure of the Lethbridge Coal Zone.

Dodson (1970, 1971), in an earlier attempt to provide similar data, used the contact between the Milk River and Pakowki formations (derived from subsurface data) to create a structural contour map from which relative stratigraphic positions of localities in Dinosaur Provincial Park could be interpreted. Preliminary data gathered during 1986 suggest that at least one major hiatus or erosional unconformity may exist at the base of the Judith River Formation sedimentary sequence exposed in Dinosaur Provincial Park. If so, and if other hiatuses or unconformities are present throughout the thick, intervening sequence between the Judith River Formation and the base of the Pakowki Formation, the structural contour data generated from the Milk River/Pakowki contact is probably less reliable than that generated from the Lethbridge Coal Zone. Nonetheless, either method should be regarded as fairly crude and in need of further refinement or replacement.

5.3.3 Sampling Procedure

The following features of each site were recorded: geometry, lithology, texture, sedimentary structures and lithofacies, lithofacies assemblages, biogenic structures, fossil content and distribution. Photographs and field

sketches of most of the localities were also produced. Each site was trenched to reveal fresh exposure. Rock samples were collected for further laboratory analysis where questions regarding diagenesis, sorting or petrology arose.

Each deposit was first defined as a discrete lithosome by delineating erosional contacts, bounding surfaces, lithological homogeneity, and grain size with respect to surrounding lithosomes. Where possible, the geometry of each lithosome was then determined by mapping using a pace and compass method and employing a brunton compass and a l... Jacob's staff with a top-mounted abney level. Lithosomes were classified as ribbons (w/d 15) or sheets (w/d 15). Among the eighteen sites surveyed during this study only two were found to be unequivocally ribbon-shaped; one more is questionably assigned to this category. The remaining fifteen sheet-shaped lithosomes comprise the bulk of the surveyed sites and were further classified on the basis of lithology, the nature of internal and external bounding surfaces, and sedimentary structures. Following Koster (1983, 1984), Wood (1985), and Visser (1986) all of the coarse grained, large-scale, erosionally-based, sheet-shaped lithosomes possessing sets of large-scale statification and intra or extraformational pebbles were interpreted as channel assemblages. Of the eighteen microsites surveyed, three occur in Type I channel lithosomes, four occur in Type II channel lithosomes and one occurs in a composite type of lithosome. The remaining seven non-channel, sheet-shaped lithosomes comprise a complex array of interchannel to channel margin deposits.

5.3.4 Interpretation

Seven representative microsite localities are briefly described and interpreted. Locality data of the bonebeds (abbreviated BB) are on file at the Tyrrell Museum of Palaeontology.

5.3.4.1 Ribbon-shaped Lithosomes

Bonebeds 54 and 100 are the only two clear examples of ribbon-shaped lithosomes among the eighteen sites surveyed. Aside from their geometries these localities share virtually no features in common.

Bonebed 54: Interpretation - Ox-bow channel-fill.

BB 54 occurs at the top of a 12m thick mudstone-filled channel in a 50cm thick, coaly, horizontally laminated unit comprising three poorly to moderately sorted, graded sequences, each 8-30cm thick. The graded beds capped by comminuted carbonized plant fragments indicate that flow in the channel was variable and intermittent. All the beds are deeply contorted suggesting locally high loads, probably a result of vertebrate trampling. Of particular interest at this locality is the association of the 12m thick mudstone/siltstone filled channel in which the microlocality lies and a laterally adjacent Type I channel assemblage. The occurrence of the mudstone/siltstone channel laterally and conformably above and adjacent to the inclined heterolithic strata of the channel assemblage indicates that this 12m thick unit represents an abandoned channel within a high sinuosity river system. BB 54 occupies a stratigraphic position high within the abandoned channel and appears to have been deposited during the final stages of channel infilling.

Bonebed 100: Interpretation - High-energy channel-fill.

BB 100 lies near the base of a ribbon-shaped lithosome which possesses two vertically stacked, erosive based, laterally tapering 'wings'. BB 100 comprises vertebrate elements and clay pebbles in association with the erosional base of the lower 'wing'. This deposit lacks many of the features

characteristic of the channel types defined by Koster and thus appears not to have been a perennially active or major channel. The presence of at least two sandstone dominated 'wings', as well as alternating sequences of sandstone and carbonaceous siltstone in the thickest portion of the channel indicates variable rates of flow. Massive, poorly sorted sediments suggest that clastics were rapidly deposited in this channel. Increasing occurrences of alternating sandstone and carbonaceous siltstones toward the main body of the lithosome indicate more frequent flooding in the deeper portion of the channel.

5.3.4.2 Sheet-shaped Lithosomes

Bonebed 51: Interpretation - Type I channel.

BB 51 occurs at the base of a 3.4-4m thick fining-upward Type I channel assemblage as indicated by the presence of low-angle inclined herolithic strata which dominate the sequence. The microvertebrate fossils occur at the erosional base of the lithosome in association with claystone pebbles and carbonized plant fragment strings in a 75m thick medium-grained, crudely laminated sandstone. Above, this lithosome fines upward into mudstone-dominated IHS.

BB 51 and 94 occur in association with a horizontally stratified sandstone, channel scours and coarse-grained, poorly-sorted sediments indicating that they were deposited in the upper flow regime. The occurrence of vertebrate microfossils in association with an erosionally based, poorly sorted, clay-pebble-rich sandstone at the base of these point-bar sequences indicates that some of the microvertebrate fossils may have been derived from underlying or adjacent lithofacies.

Bonebed 102: Interpretation - Type II channel.

BB 102 occurs in association with crudely-stratified, poorly-sorted, pebbly sediments at the erosional base of a largely trough cross-stratified, 6m thick sandstone body. This association indicates that the initiation of flow in this channel was accompanied by significant scour of underlying sediments. Sediment and fossils were transported in the upper flow regime and deposited as plane beds. Further reduction in flow velocities resulted the establishment of large-scale dune bedforms on the channel floor. The occurrence of a microvertebrate assemblage at the erosive base of a Type II channel assemblage indicates that many of the elements may be reworked from underlying sediments.

Bonebed 108: Composite Interpretation - Composite channel type, lag deposit.

BB 108 comprises a number of trough cross-strata at the base of a Type III channel assemblage. The BB 108 lithosome is approximately 4-5m thick and is a generally upward-fining unit. Vertebrate microfossils and claystone intraclasts produce from the lowest 20cm of a 2.5m thick sequence of trough cross-stratification. In vertical profile, IHS units appear to abruptly overlie this 2.5m thick sequence of trough cross-strata, however, laterally and downdip, the inclined heterolithic strata gradually pass into the trough cross-strata. IHS units possess upward increasing amounts of carbonized plant matter in their fine-grained laminae.

The presence of vertebrate microfossils at the base, of and within the trough cross-stratified pebbly sandstones indicates that they were transported as bedload during the downstream movement of subaqueous in-channel dunes and were preserved as lag in the troughs preceeding the avalanche slopes of the dunes.

Bonebed 31: Interpretation - Crevasse Splay.

BB 31 occurs within a 1.5m thick fining-upward unit of highly contorted carbonaceous sediments which display a crude horizontal lamination, and possesses a locally concentrated deposit of disarticulated pisidiid clam valves. A sheet-shaped geometry, the presence of horizontally stratified sediment as well as the absence of scour and lag deposits and large-scale stratification all indicate that the lithosome was deposited in a non-channel, relatively quiet water environment. Small-scale sandstone lenses and laminae are present and together with disarticulated microvertebrate and invertebrate fossils indicate occasional high flow velocities. Numerous abrupt contacts between laminae and lenses indicate that this area was repeatedly innundated by flood waters but the fining-upward nature of the deposit, as well as the thinning-upward nature of the beds and laminae suggests that, through time, this area was abandoned. The locally dense accumulation of disarticulated pisidiid valves is of particular interest in this deposit. The limited lateral extent of the shell horizons of approximately 10m, in contrast to the relatively extensive nature of the horizontal strata (more than 50m), indicates that the pisidiid's source bed(s) must have been very close to the depositional site. Inspection of the adjacent and underlying fine-grained facies have failed to yield any evidence of <u>in situ</u> pisidiids. However this is not unexpected because, to date, all known occurrences of invertebrates with aragonite shells in Dinosaur Park have been found within uncompacted ironstone beds suggesting that it is only in these early diagenetic chemical environments that shells have been protected from dissolution. Locally concentrated pisidiid valves suggests that intermittent flood waters swept through a local community of pisidiid clams. After each flood, the

invertebrate community was reestablished. Over time, either flood waters became less competent carrying fewer clams, or the invertebrate community disappeared or was re-established elsewhere.

Bonebed 107: Interpretation - ? levee sequence.

BB 107 occurs in a fining-upward sequence of sandy siltstone. Mudstone intraclasts occur in association with the microfossils at the base of the deposit. Sediments are all highly contorted suggesting vertebrate trampling. The deposit passes laterally (and toward source) into a 2m thick, horizontally bedded, ripple-laminated, fine-grained sandstone unit. This portion is erosionally overlain by a thick sequence of large-scale trough cross-beds. The ripple-laminated, horizontally bedded portion of the unit is very reminiscent of levee sequences.

5.3.5 Faunal Analysis

The facts that 1) microvertebrate elements represent only a tiny fraction of the original skeletons of any taxon and 2) that there is, in general, a close correspondence between the hydraulic equivalency of the elements and the clasts of the encasing rock indicate that the microfossil assemblages are allochthonous, sorted assemblages (Wolff, 1973; Behrensmeyer, 1975; Korth 1979; Hanson, 1980). Clearly, the effects of sorting and transport on fossil elements precluded interpretation of original faunal proportions (Shotwell, 1955, 1958; Wolff, 1973; Dodson, 1973; Korth, 1979). Thus an attempt is not being made to reconstruct the composition and proportions of animals in an individual community. However, microsites differ in the relative abundance of taxa. By comparing of many sites, patterns can be recognized and correlated with such features as stratigraphic position and environment of deposition.

In this study, we are attempting to define these patterns and identify aspects of the pattern that have an ecological basis.

Twenty-three taxa of aquatic vertebrates have been identified. Most are generically or specifically identical to taxa from the Judith River Formation of Montana (Sahni, 1972) but surprisingly, some of the more important members of the Dinosaur Park microvertebrate fossil assemblage have not yet been reported from localities in Montana. Of particular note are two types of holostean fish represented by scales, designated holostean A and B, and a distinctive teleost jaw element.

The analysis is restricted to 14 sites in which samples of over 200 specimens were obtained. A cluster analysis was used to group sites according to the similarity in relative abundances of different kinds of animals present (Fig. 38). There is, however, a poor correlation between kinds of fossil assemblages present and local depostional environment. For example, BB 51 and BB 94 represent accumulations in very similar environments of deposition, but significant differences are seen in the relative abundances of different kinds of animals at the two sites while BB 51, a channel deposit, and BB 100, a crevasse splay, have similar faunal assemblages. Thus a number of different factors must be considered in accounting for the different fossil assemblages.

In order to identify these factors, groups of animals that tend to occur together were identified by conducting a cluster analysis on the animals preserved in the 14 sites sampled, and the stratigraphic and paleoenvironmental correlates of these groups considered. Three main clusters are present (Fig. 39). These will be referred to as the Scapherpeton cluster, the holostean A cluster, and the Myledaphus cluster after the most abundant members in each group.

Two clusters, the Scapherpeton cluster and the holostean 'A' cluster, are well represented at all sites. Both Scapherpeton and holostean 'A' are among the five most abundant animals in all sites examined. One locality (BB 54) is present in which members of the holostean 'A' cluster are particularly abundant. The depositional environment at this locality is not duplicated at other sites in the Park, so it is impossible to interpret whether or not this represents a significant ecological pattern. One member of the holostean cluster, the teleosts, shows a decrease in abundance relative to Scapherpeton through the stratigraphic section (Fig. 40). This presumably reflects an overall environmental change through the section, although the nature of this change cannot be identified at present.

Considered in relationship to members of the Scapherpeton and holostean 'A' clusters, members of the Myledaphus cluster tend to show an increase in abundance through the stratigraphic section (Fig. 41). They also show a tendency to be more abundant in channels, of which Myledaphus is an extreme case (Fig. 6). It occurs throughout the section. In overbank localities, it is rare relative to Scapherpeton, and in channel deposits, it shows an increase throughout the section relative to Scapherpeton.

These stratigraphic changes presumably reflect an overall change in environment through the section. An increase in the tidal influence higher in section is one possible explanation. Myledaphus and Atractosteus are both animals that, on the basis of the habitats favored by living relatives, have been throught to be brackish water indicators. The tendency for Myledaphus and associated animals to be found more abundantly in channel deposits suggests that they were members of a community that favored channels.

While the ecological basis for some of these patterns may always be a matter of speculation, identification of the patterns themselves gives a better understanding of the palaeoecological complexity of Upper Cretaceous non-marine aquatic ecosystems. They also provide a basis for considering changes in faunal composition through the Upper Cretaceous from a paleoecological perspective.

5.4 Non-Marine Mollusca

5.4.1 Previous Work

Apart from a brief mention by Dodson (1971), Judithian non-marine molluscs from Dinosaur Provincial Park have not been the subject of published taxonomic or palaeoecological studies. Major taxonomic treatments of non-marine molluscs from the Judith River Formation exposed elsewhere include Meek (1876), White (1877, 1883) and Whiteaves (1885). Subsequently, extensive taxonomic lists of molluscs known from this Formation were provided by Stanton and Hatcher (1905), Williams and Dyer (1930), Henderson (1935), Russell (in Russell and Landes, 1940) and most recently by Russell (1964). Russell's (1964) list of representative non-marine molluscs from the upper part of the Judith River Formation exposed on the Milk, Saskatchewan and Red Deer Rivers is reproduced as Table 4, with slight emendations and with higher classification added.

5.4.2 Molluscan Assemblages

Although locally abundant at several sites, non-marine molluscs are, on the whole, a relatively rare component of the preserved biota of Dinosaur Provincial Park. Preliminary examination of known occurrences indicate at least two discrete mollusc assemblages.

5.4.2.1 Pisidiid-dominated assemblage

Three sites, including BB31, (see Section 5.3.4.2), are dominated by abundant remains of the small, thin-shelled pisidiid bivalve, Sphaerium recticardinale Meek and Hayden. Small gastropods (mostly Goniobasis sp.) form a lesser component and unionid shells (invariably disarticulated) are rare. With few exceptions, the pisidiid shells are disarticulated and many are fragmentary indicating at least moderate reworking. Living pisidiids typically inhabit ephemeral or permanent lentic (quiet-water) environments. (Hanley, 1976).

5.4.2.2 Unionid-dominated assemblage

More common are sites dominated by abundant remains of much larger, heavy-shelled, unionid bivalves (mostly Fusconaia? danae [Meek and Hayden]) preserved in channel sands. The frequency of complete, articulated, often vertically oriented specimens at these sites indicates minimal reworking or transport. Living unionids typically inhabit well-oxygenated permanent, lotic (flowing-water) environments (Hanley, 1976). Except for a single, unionid-dominated locality (L1209) approximately 20-25m below the Lethbridge Coal Zone, known occurrences of non-marine molluscs in Dinosaur Provincial Park are restricted to the lower half of the exposed section of the Judith River Formation.

The unionid-dominated assemblages are commonly associated with unusual, bulbous, sedimentary structures, here interpreted as burrows of unionid bivalves, primarily F.? danae. The burrows are especially well-developed at TMP locality L1203 (Fig. 42A-E) where they protrude from the underside of a shelving sandstone that overlies a usually more recessive unit with abundant unionid shells (Fig. 42A). Densities of up to 200 burrows per square metre

have been observed (Fig. 42B). The burrows are typically ovoid to cordate in outline and bear a heavy ridge (sometimes multiple ridges) that is coincident with the long axis of the burrow outline (Fig. 42C). Vertical faces of the shelving sandstone show the burrows extending upward through the bed as poorly defined shafts that are filled with meniscate laminae (Fig. 42D). Exposed cross-sections of the shafts are ovoid in outline and, like the bulbous structures at the base of the bed, tend to be aligned with the narrow ends of the outlines facing the same direction (Fig. 42E). Shells (or steinkerns) of F.? danae occur somewhat sporadically at the base of the sandstone but none have been observed within the burrows. Instead, the shells are usually oriented with the long axis of the shell parallel to bedding and roughly parallel with the burrow outlines (Fig. 42B,C; see also specimen TMP 86.206.1 on display in the Field Station of the Tyrrell Museum of Palaeontology). Within the shelving sandstone, shells may or may not occur depending on the locality. When present, the shells are usually articulated and occur in apparently random orientations.

Modern river-dwelling unionaceans, such as Margaritifera margaritifera (Linne), lack siphons (as do all members of the Unionacea) and consequently are shallow burrowers with about a half to a third of the shell length exposed above the sediment/water interface (Trueman, 1968; Thoms and Berg, 1985). In life, these animals show a preferred orientation with the sagittal plane of the shell parallel to current flow and the exhalent area of the shell margin on the downstream side of the inhalent area to avoid recycling of expended water and fecal material. The long axis of the shell dips downstream. By analogy, a similar life mode is here inferred for F.? danae (Fig. 42F).

Experiments with living M. margaritifera show that inundation by sediment prompts an upward escape response produced by downward thrusts of the foot; however, data are unavailable as to the sedimentary structures generated (Thoms and Berg, 1985). The phenomenon is better known for marine bivalves for which laminae-filled escape shafts have been observed (Kranz, 1974; Howard, 1975). Upward escape rates for bivalves including M. margaritifera, are normally on the order of a few centimetres per hour (Kranz, 1974; Thoms and Berg, 1985). Fossil burrows attributed to upward-escaping, non-marine bivalves have been recorded from Devonian and Carboniferous rocks but were hitherto unknown from post-Palaeozoic rocks (Berg, 1973, 1977: Eagar 1974, 1978; Thoms and Berg, 1974, 1985; Hardy and Broadhurst, 1978; Bridge et al., 1986).

By analogy with the Recent and Palaeozoic examples cited above, the bulbous structures shown in Figure 42 A-D are here interpreted as domichnia (dwelling structures) and the laminae-filled shafts as fugichnia (escape structures) of unionids (primarily F.? danae) (see Simpson, 1975 for terms). The hypothesized generation of these structures is indicated in Figure 42Fiii. The prominent ridge (sometimes ridges) on the long axis of the domichnia (Fig. 42C) (not discussed in the aforementioned studies) probably represents the initial thrust mark (or marks) of the foot at the onset of upward escape. At some localities (eg. L1203) abundant shells occur in the beds immediately above the shelving sand or (eg. L1205) on the upper surface of the shelving sand. In these instances the shells are almost invariably articulated with the hinge undermost and the valves gaping (see TMP 86.229.1 on display in the Field Station). These observations suggest that the

bivalves expired after their upward escape, perhaps from a drop in water level and consequent subaerial exposure. The shells were subsequently buried before disintegration of the ligament tissue that unites the valves.

From the above interpretations, there follows several implications for vectorial analyses of associated rock units: 1) aligned domichnia (Fig. 42C) and aligned cross-sectional outlines of fugichnia (Fig. 42E) indicate unidirectional flow; 2) the outlines of domichnia and the cross-sectional outlines of fugichnia compare closely with the cross-sectional outline of slightly gaping shells of F.? danae (compare Fig. 42C,E with Fii) - consequently, the narrow end of these structures can be taken to indicate the upstream direction; 3) where the outlines of domichnia are weathered or otherwise poorly preserved, the thrust mark of the foot can be used to indicate paleocurrent direction as this structure occurs toward the narrow, or upstream, end of well-preserved domichnia (Fig. 42C), a feature anticipated from the fact that the foot in unionaceans emerges along the anteroventral margin of the shell (Fig. 42 Fiii).

5.5 Palynology

Upper Cretaceous strata in the Drumheller and Dinosaur Provincal Park areas have been studies for over a century but the plant fossils, particulary megaplants, are not yet documented in any detail. Some of the known plants have been illustrated in Bell (1949, 1965), but the nomenclature is probably dated and no comprehensive recent work is available.

The Edmonton Group (including Horseshoe Canyon, Whitemud, Battle and Scollard formations) has a better known paleoflora than the Judith River Formation, although most of this information comes from palynological

sources. A summary of the palynology is provided by Srivastava (1970), who divides the group into nine assemblages zones. Twenty-three families of angiosperms alone have been described. The assemblages belong to what has been described as the Aquilapollenites floral province (Herngreen and Chlonova, 1981). Within the Horseshoe Canyon Formation, a number of megaplant fossil sites are known. Common megaplants include Metasequoia (both leaves and cones), Nilssonia, Ginkgo and Cercidiphylum. Numerous localities provide abundant wood, mainly derived from conifers. Both stumps and trunks occur and concentration of in situ stumps have been described as fossil forest. Srivastava (1970) postulated that the climate changed from humid subtropical at the start of Edmonton deposition to warm temperatures near the end.

At Dinosaur Provincial Park, the Judith River Formation contains relatively little macrofossil material (Table 5). The main kinds appear to be Taxodiaceae, Cupressaceae, Measequoia, and Cercidiphyllum. Well-preserved leaf floras are associated with channel sandstones, interchannel mudstones and ironstone concretions. As noted in section 4.3.3, early-formed concretions commonly preserve uncompacted leaves and wood fragments. Macrofloral remains in channel sediments, with the exception of abraded large logs of coniferous trees, are generally compressed and totally carbonized. Amber is also quite commonly encountered in laminated channel sands, and in a few localities attains high concentration. The most common form of macrofloral remains within mudstone units are unidentifiable flecks of carbonized plant material and thin rootlet systems. In-situ tree roots, compared to the Drumheller area, are exceedingly rare.

Plant microfossils give a more detailed picture of the paleofloras (Table 6). Jarzen (1982) described palynomorphs recovered from turtle shell matrix and sediment samples. He listed a total of 85 taxa from the Park representing mosses, hornworts, liverworts, club mosses, Selaginellales, ferns, cycads, conifers, Ephidraceae and a wide variety of angiosperms typical of the Aquilapollenites floral province (Herngreen and Chlonova, 1981). Waldman and Hopkins (1970) recovered a suite of palynomorphs from coprolites interpreted as being from a carnivore. The meagre fossil plant record appears to indicate a warm humid temperature or subtropical climate in Alberta during the Campanian.

6.0 SUMMARY OF EXCURSION

For the several reasons outlined by the Introduction, this section provides only a brief summary of the features to be examined during the excursion. The guidebook has focussed on 1) the form, processes and facies of paleochannels, 2) their local depositional setting in the broader context of basin analysis and 3) the paleoecological and taphonomic contexts of vertebrate, non-marine molluscan and floral assemblages.

The following features are listed mainly according to the anticipated schedule of the excursion. During hikes it is important, for reasons of safety and schedule, that everyone remain in sight of the rest of the group and move on when requested. The schedule involves vehicle travel on roads and trails and hikes up to several kilometres. Both public and Natural Preserve areas will be visited over a range of elevations to help convey the spatial and temporal variation in depositional paleoenvironments and paleoecological conditions.

Topic of stops	Relevent sections in guidebook
1. Tyrrell Museum of Palaeontology, Drumheller	Foreword
2. Field Station of the Tyrrell Museum, Dinosaur Provincial Park area -	Foreword
3. Review of local stratigraphy, basin paleogeography and -climate, tectonic structure.	2.3.2, 3.0
4. Holocene development of the badlands.	2.3
5. Fluvial processes in the Red Deer River, Sandhill Creek and an ephemeral creek.	2.3.1
6. Coarse- and fine-member composition of the coastal plain sequence.	4.3.1
7. Field techniques for data gathering in continuously exposed terrain.	4.2, 5.3.3
8. Laterally-accreted paleochannel sequences.	4.3.2.1, 4.4.3
9. Vertically-aggraded, sand-dominant paleo-channel sequences.	4.3.2.2, 4.4.4
10. Composite paleochannel sequences.	4.3.2.3
11. Inter-channel sequences.	4.3.3, 4.4.2, 5.5
12. Amalgamation of coarse members.	4.3.2.4, 5.2
13. Molluscan assemblages.	5.4,
14. Quarries, bonebeds and microsites.	5.1, 5.2, 5.3,

15. Mortality, destruction and facies-controlled preservation modes of vertebrates.	5.2, 5.3
16. Lethbridge Coal Zone and Bearpaw Formation.	2.3.2, 3.3, 3.6.1, 5.3.2
17. Discussion of cause-and-effect in the sedimentary and fossil record of the coastal plain.	3.2, 3.3, 3.4, 4.4, 5.0

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9.0 TABLES AND FIGURES

TABLE 1: Faunal Assemblage from Park area outcrops with number of known species (Koster and Currie, in press).

Subaerial		Freshwater	
Herbivorous dinosaurs	22	Fish	14
Mammals	20	Mesoreptiles:	
Carnivorous dinosaurs	17	Turtles	11
Lizards	11	Crocodiles	4
Flying reptiles	2	Champsosaurs	1
Birds	1	Salamanders	7
		Frogs	3
		Molluscs	2

Marine	
Fish	2
Plesiosaurs	1
? Unreworked plankton	

TABLE 2: Vertebrate faunal list of the Upper Judith River Formation at Dinosaur Provincial Park.

CHONDRICHTHYES		
Holocephali		
Chimaeriformes	Chimaeridae	Ischyodus bifurcatius
	Rhiochimaeridae	Elasmodus cf greenoughi
Elasmobianchii		
Selachii	Hybodontidae	Hybodus montanensis
		Hybodus storeii
Euselachii	Synechodontidae	Synechodus andersoni
		Synechodus striatus
	Anacoracidae	Squalicorax kaupi
	Orectolobidae	Eucrossorhinus microcuspidatus
		Cretorectolobus olsoni
	Hemiscyllidae	Chiloscyllium missouriensis
	Odontaspidae	Hypotodus grandis
		Odontaspis sangiunei
	Cretoxyrhinidae	Plicatolamna arcuata
	Pseudotriakidae	Archaeotreakis rochelleae
Rajiformis	Rhinobatidae	Protoplatyrhina renae
Batoidae	Sclerochynchidae	Ichthyrhiza cf avonicola
		Ichthyrhiza mira
	Incertae Sedis	Ptychotrygon blainensis
	Dasyatidae	Myledaphus bipartitus

OSTEISHTHYES		
Acipenseriformes	Acipenseridae	Acipenser albertensis
	Polyodontidae	Paleopsephurus sp.
Aspidorhynchiformes	Aspidorhynchidae	Belonostomus longirostris
Lepisosteiformes	Lepisosteidae	Atractosteus occidentalis
Amiiformes	Amiidae	Kindlea sp.
?Amiiformes	incertoes sedis	gen et sp unident (Holostean A)
		gen et sp unident (Holostean B)
Elopiformes	Elopidae	Paratarpon apogerontus
	Albulidae	Coriops amnicolus
?Elopiformes	Phylodontidae	Paralbula casei
Osteoglossmorpha	incertae sedis	cf. Chandlerichthyes
?Acanthopterygii	incertae sedis	Platacodon sp.
Acanthopterygii	incertae sedis	gen et sp inident
AMPHIBIA		
Salientia	Ascaphidae	Gen. et sp. nov.(Fox)
	Discoglossidae	cf. Scotiophyrne
	Pelobatidae	Eopelobates
Caudata	Scapherpetontidae	Scapherpeton tectum
		cf. Lisserpeton bairdi
	Amphiumidae	Proamphiuma sp.
	Batrachosauroididae	Opisthotriton kayi
		Prodesmodon copei
	Sirenidae	Habrosaurus dilatus
Allocaudata	Albanerpetontidae	Albanerpeton sp.
REPTILIA		
Chelonia	Baenidae	Neurankylus eximus
		Boremys pulchra
		Naomichelys
		Plesiobaena antiqua
	Macrobaenidae	"Clemmys" cf. C. bachmani
	Dermatemydidae	Adocus lineolatus
		Basilemys variolosa
	Trionychidae	Aspideretes foveatus
		Aspideretes alleni
	Chelydridae	Gen. et sp. indet.
Sauropterygia	Polycotylidae	Gen. et sp. indet.
Archosauromorph	Champsosauridae	Champsosaurus natator
Sauria	Teiidae	Chamops
		Leptochamops denticulatus
	Scincidae	Sauriscus
	Anguidae	Pancelosaurus
	Xenosauridae	Gen. et sp. indet.
	Necrosauridae	Parasaniwa
		Paraderma
		Colpodontosaurus
	Varanidae	Palaeosaniwa canadensis
Sauria inc. sed.		Gen. et sp. nov.(Fox)
Ophidia	Aneliidae	Coniophis

Crocodilia	Crocodylidae	Leidyosuchus canadensis
		cf. Brachychampsa
		Albertochampsa langstoni
	Sebecosuchian	Gen. et sp. indet.
Pterosauria	Pterodactyloidea	Quetzalcoatlus sp.
		Gen. et sp. indet.
Saurischia	Segnosauridae	cf. Erlikosaurus
	Ornithomimidae	Dromiceiomimus samueli
		Ornithomimus edmontonicus
		Struthiomimus altus
	Troodontidae	Troodon formosus
		(Stenonychosaurus inequalis)
		(Pectinodon bakkeri)
	Dromaeosauridae	Dromaeosaurus albertensis
		Saurornitholestes langstoni
	cf. Dromaeosauridae	(Paronychodon lacustris)
	Caenagnathidae	Caenagnathus collinsi
		Caenagnathus sternbergi
	cf. Caenagnathidae	Chirostenotes pergracilis
		(Macrophalangia canadensis)
		(Macrophalangia elegans)
		Elmisaurus
	Tyrannosauridae	Albertosaurus libratus
		Daspletosaurus torosus
		Gracile tyrannosaur
		(Aublysodon sp.)
		(undescribed)
Ornithischia	Hadrosauridae	Brachylophosaurus canadensis
		Gryposaurus notabilis
		Kritosaurus incurvimanus
		Prosaurolophus maximus
		Corythosaurus casuarius
		Lambeosaurus lambei
		Lambeosaurus magnicristatus
		Parasaurolophus walkeri
	Pachycephalosaurid	Gravitholus albertae
		Ornatotholus browni
		Pachycephalosaurus sp.
		Stegoceras validus
		Full Domed form, undescribed
	Nodosauridae	Panoplosaurus mirus
		Edmontonia longiceps
	Ankylosauridae	Euoplocephalus tutus
	Ceratopsidae	Anchiceratops sp.
		Centrosaurus apertus
		Chasmosaurus belli
		Chasmosaurus kaiseni
		Eoceratops canadensis
		Monoclonius lowei
		Styracosaurus albertensis

AVES		
cf. Neognathae		Gen. et sp. indet.
MAMMALIA		
Multituberculata	Neoplagiaulacidae	Cimexomys judithae
		Mesodma primaeva
	Cimolodontidae	Cimolodon electus
		Cimolodon similis
	Cimolomyidae	Cimolomys clarki
		Meniscoessus major
		Gen. et sp. indet.
Theria inc. sed.	Deltatheridiidae	cf. Deltatheroides
Marsupialia	Didelphidae	Alphadon praesagus
		Alphadon halleyi
		Alphadon, n. sp.
	Pediomyidae	Pediomys clemensi
		Pediomys, n. sp.
	Stagodontidae	Boreodon matutinus
		Eodelphis cutleri
		Eodelphis browni
Eutheria/Insectivora	Leptictoidea	Gypsonictops lewisi
	cf. Nyctitheriidae	Paranyctoides sternbergi
	Palaeoryctidae	Cimolestes sp.
		Gen. et sp.nov.(Fox)

Table 3: Comparison of the proportions of dinosaur remains in microsites and as represented by articulated specimens (P. Dodson written communication). Adjusted proportions (second column) are the porportions of dinosaurs exclusive of pachycephalosaurids.

	ARTICULATED	ADJUSTED	MICROFAUNA
Hadrosaur	41.0%	45.5%	45.0%
Ceratopsian	22.3%	24.7%	26.4%
Anklysosaur	11.9%	13.3%	8.2%
Pachycephalosaur	10.0%	---	0.1%
Coelurosaur	3.2%	3.6%	4.9%
Ornithomimid	4.8%	5.4%	2.3%
Tyrannosaur	6.8%	7.5%	13.1%
Total theropod	14.8%	16.5%	20.3%
Number of specimens	310	279	4931

TABLE 4: Representative non-marine molluscs of the upper Judith River Formation slightly amended from Russell (1964); higher taxonomic assignments based on Moore (1969) for bivalves and LaRocque (1953) and Hartman (1984) for gastropods.

Class Bivalvia
  Subclass Palaeoheterodonta
    Order Unionoida
      Family Unionidae
        Pleurobema? humei (Dyer)
        Rhabdotophorus senectus (White)
        Anodonta propatoris (White)
        Quadrula? primaevus (White)
        Lampsilis? consueta (Whiteaves)
        Fusconaia? danae (Meek and Hayden)
  Subclass Heterodonta
    Order Veneroida
      Family Pisidiidae
        Sphaerium recticardinale Meek and Hayden
    Order Myoida
      Family Corbulidae
        Corbula confiniensis Russell
Class Gastropoda
Subclass Prosobranchia (gill-breathing, aquatic snails)
  Order Mesogastropoda
    Family Viviparidae
      Viviparus nidaga Dyer
    Family Hydrobiidae
      Micropyrgus higdoni (Russell)
    Family Pleuroceridae
      Lioplacodes praecursa (Dyer)
      L. judithensis (Stanton)
      Goniobasis sublaevus (Meek and Hayden)
      G. gracilenta (Meek and Hayden)
Subclass Pulmonata (Lung-breathing snails)
  Order Basommatophora (Predominately aquatic species)
    Family Physidae
      Physa canadensis Whiteaves
  Order Stylommatophora (Terrestrial species)
    Family Polygyridae
      Polygyra venerabilis Russell
    Family Grangerellidae
      Prograngerella sperata Russell

TABLE 5: Record of megaplant fossils from the upper Judith River Formation from Bell (1965).

Artocarpus sp.
Dombeyopsis nebrascensis
Elatocladus albertaensis
Menispermites sp.
Platanus affinis
Platanus latiloda
Sequoia sp.
Vitis stantoni

TABLE 6: Record of palynomorph species form the upper Judith River Formation at Dinosaur Provincial Park with suggested botanical relationships. Listed taxa have been taken unedited from Jarzen (1982), denoted J, and Waldman and Hopkins (1970), denoted W.

BRYOPHYTA	
Family Sphagnaceae	
	Cingutriletes clavus (J)
	Stereisporites antiquasporites (J)
ANTHOCEROTOPHYTA	
Family Anthocerotaceae	
	Foraminisporis wonthaggensis (J)
HEPATOPHYTA	
Family Spaerocarpaceae	
	Aequitriradites ornatus (J)
	A. spinulosus (J)
MICROPHYLLOPHYTA	
Lycopodiales	
Family Lycopodiaceae	
	Lycopodiumsporites sp. (W)
	Retitriletes austroclavatidites (J)
	R. nidus (J)
Selaginellales	
Family Selaginellaceae	
	Acantotriletes varispinosus (J)
	Heliosporites kemensis (J)
	Neoraistrickia truncatus (J)
PTERIDOPHYTA	
Filicales	
Family Osmundaceae	
	Baculatisporites comaumensis (J)
	Osmundacidites wellmanii (J)

Family Schizaeaceae

Cicatricosisporites hallei (J)
cf. *Klukisporites* sp. (W)
Lygodiosporites sp. (W)
cf. *Schizaea* sp. (W)

Family Gleicheniaceae

Gleicheniidites senonicus (J)
Gleicheniidites sp. (W)

Family polypodiaceae

Laevigatosporites adiscordatus (J)
L. discordatus (J)
L. druggii (J)
L. ovatus (J)
L. sp. (W)
L. sp. (W)
Polypodiisporites amplus (J)

Family Cyatteaceae/Dicksoniaceae

Cyathidites australis (J)
C. minor (J)

Insertae sedis

cf. *Triplanosporites* sp. (W)

CYCADOPHYTA

Cycadales

Cycadophytus nitidus (J)

Pteridospermales

Family Caytoniaceae (extinct)

Vitreisporites pallidus (J)

CONIFEROPHYTA

Conferales

Family Pinaceae

Alisporites bilateralis (J)
Cedripites cretaceus (J)
cf. *Pinus* sp. (W)
Pityosporites sp. (J)
Tsugaepollenites sp. (W)

Family Podocarpaceae

Parvisaccites radiatus (J)
Podocarpidites granulatus (J)

Family Phyllocladaceae

Lygistepollenites sp. (J)

Family Taxodiaceae/Cupressaceae

Taxodiaceaepollenites hiatus (J)

GNETOPHYTA

Family Ephedraceae

Equisetosporites multicostatus (J)

ANTHOPHYTA

Family Buxaceae

Erdtamanipollis procumbentiformis (J)

Family Cercidiphyllaceae

Cerdidiphyllites brevicolpatus (J)

Family Gunneraceae	
	Tricolpites reticulatus (J)
Family Liliaceae	
	Liliacidites mirus (J)
	L. morrinensis (J)
	L. varigatus (J)
	L. sp. (W)
	L. sp. (W)
Family ?Araceae	
	Arecipites sp. (W)
Family Typhaceae	
	Typha sp. (W)
Family Loranthaceae/Santalaceae	
	Aquilapollenites amplus (J)
	A. asper (J)
	A. attenuatus (J)
	A. calvus (J)
	A. clarireticulatus (J)
	A. pyriformis (J)
	A. quadrilobus (J)
	A. reticulatus (J)
	A. trialatus (J)
	A. tripodiformis (J)
	A. turbidus (J)
	A. sp. (W)
	Cranwellia striata (J)
	Loranthacites catteralli (J)
	Scollardia sp. (W)
Family Protaeceae	
	Beaupreaidites angulatus (J)
	B. occulatus (J)
	Proteacidites thalmanii (J)
Family Symplocaceae	
	Symplocoipollenites vestibulum (J)
Family ?Anacardiaceae	
	Pulcheripollenites narcissus (J)
Insertae sedis	
	Tricolpopollenites sp. 1 (W)
	T. sp. 2 (W)
	T. sp. 3 (W)
	T. sp. 4 (W)
	T. sp. 5 (W)
	T. sp. 6 (W)
	Tricoloporopollenites sp. 1 (W)
	T. sp. 2 (W)
	T. sp. 3 (W)
	T. sp. 4 (W)
	T. sp. 5 (W)
	T. sp. 6 (W)
	T. sp. 7 (W)

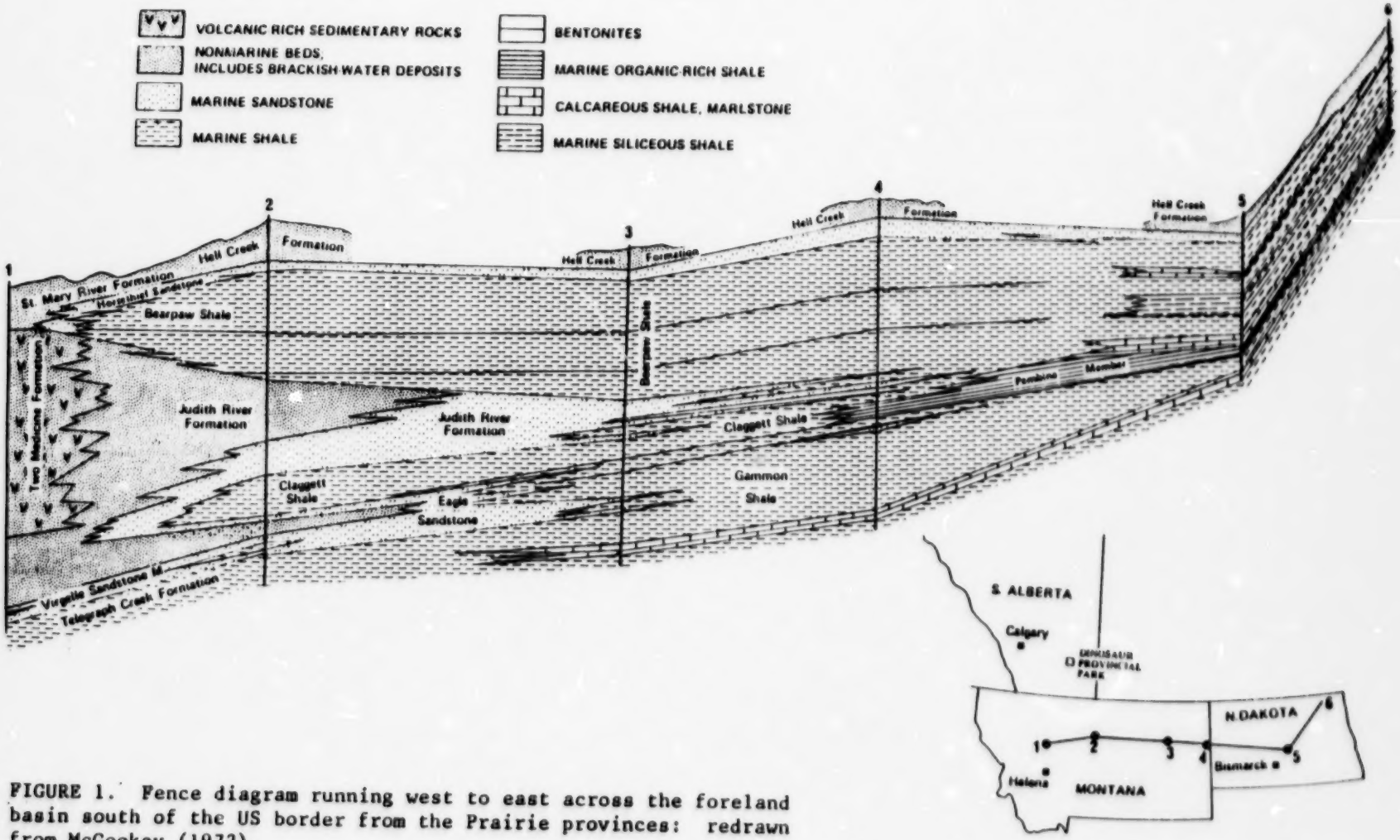


FIGURE 1. Fence diagram running west to east across the foreland basin south of the US border from the Prairie provinces: redrawn from McGookey (1972).

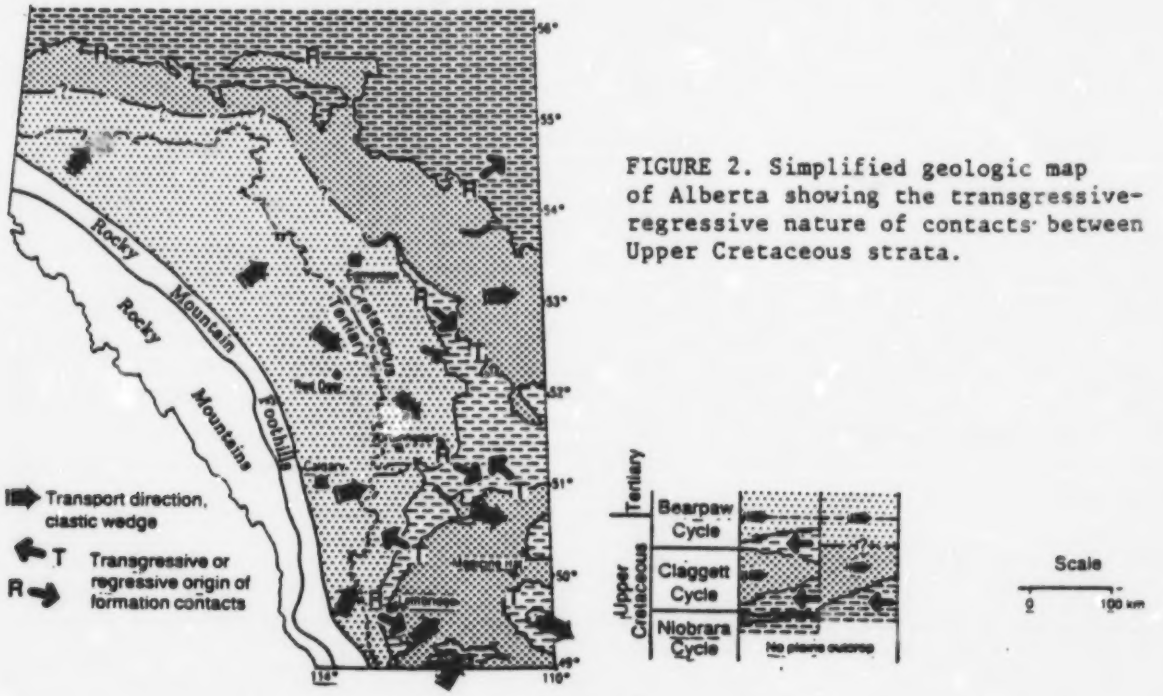


FIGURE 2. Simplified geologic map of Alberta showing the transgressive-regressive nature of contacts between Upper Cretaceous strata.

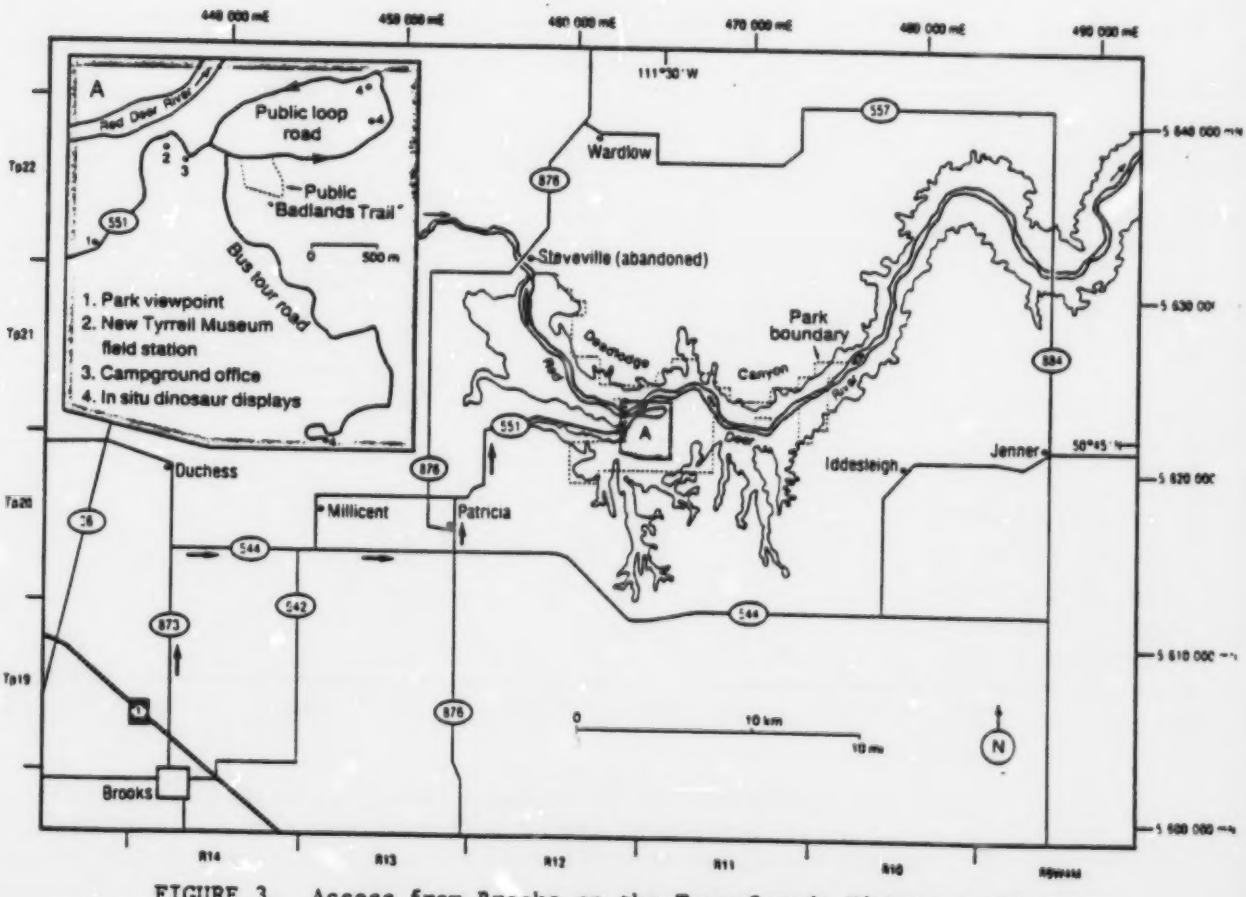


FIGURE 3. Access from Brooks on the TransCanada Highway to Dinosaur Provincial Park. The insert A shows the location of principal features within the Park headquarters area. The irregular line enclosing the course of the Red Deer River shows the distribution of badlands.

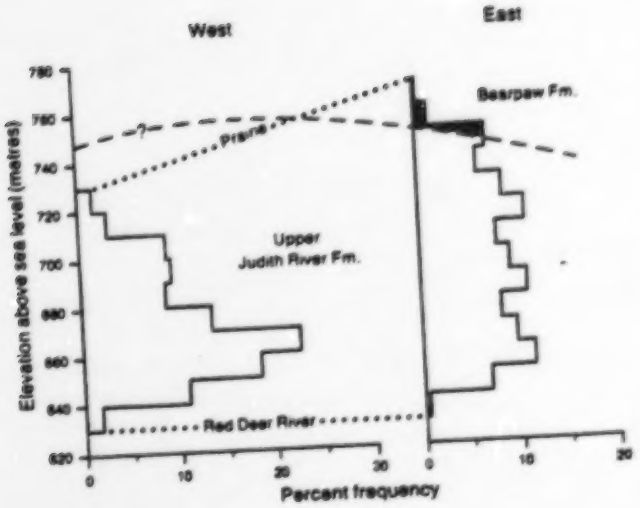


FIGURE 4. Hypsometry of the badlands in the Park area.

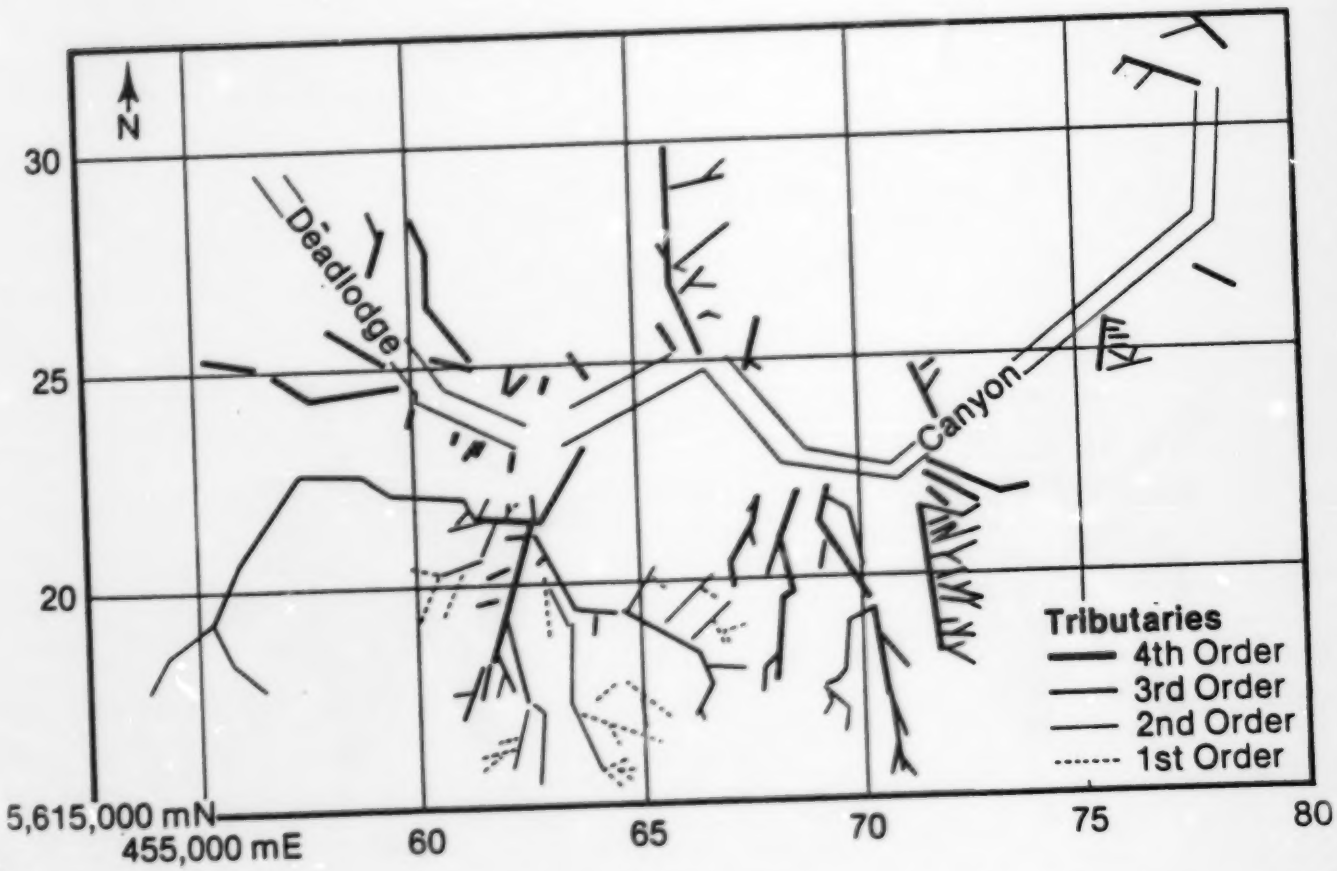


FIGURE 5. Traces of linear segments of coulees within the Park badlands, categorised according to the geomorphic order of tributary drainage to the Red Deer River in Deadlodge Canyon.

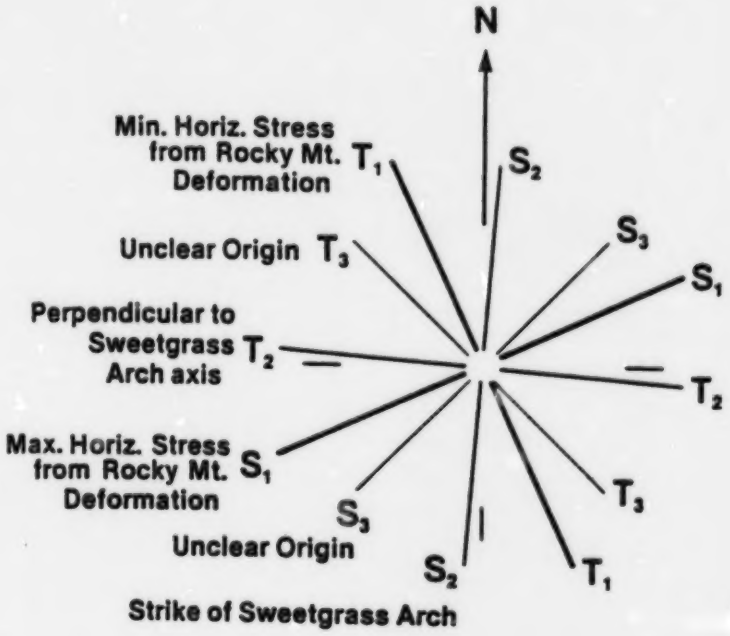


FIGURE 6. Orientation and cause of bedrock joint sets in southern Alberta, based on Babcock (1973) and Bell and Gough (1981).

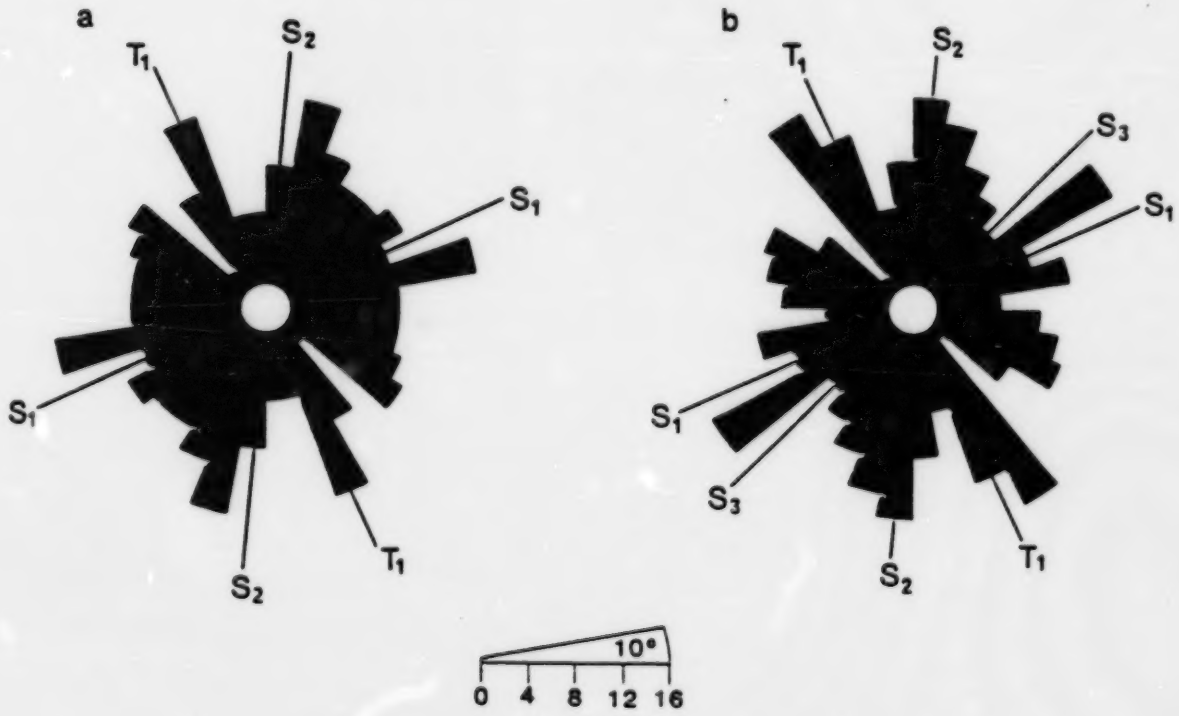


FIGURE 7. Orientation analysis of the data shown in Figure 5. a) Raw data. b) Data weighted according to length of drainage segment which, according to Curray's (1956) method, is statistically significant.

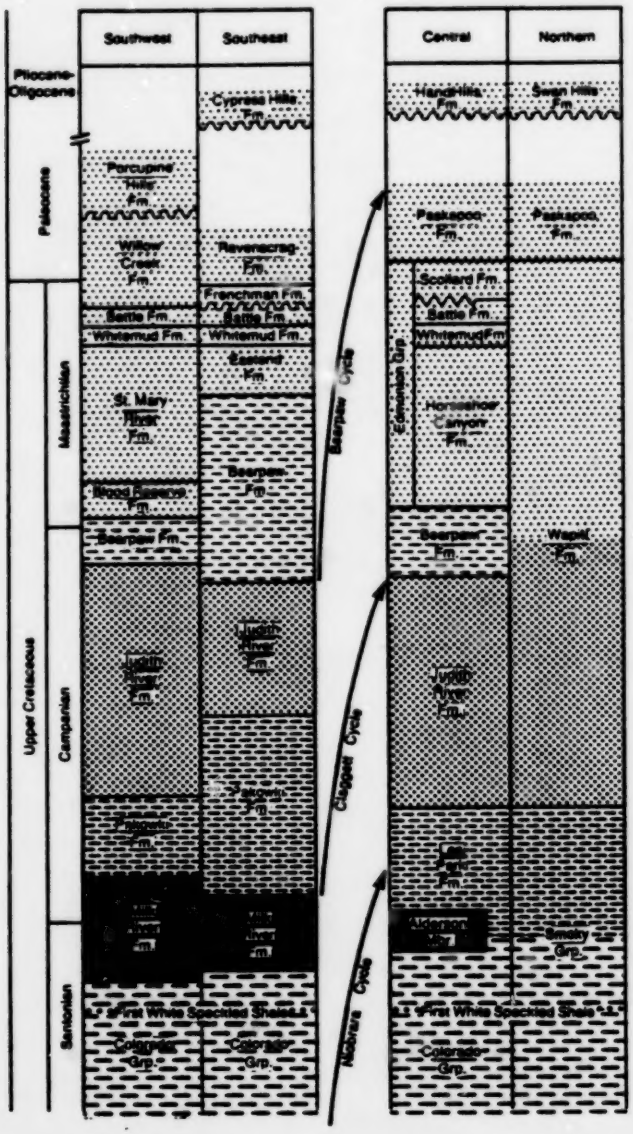
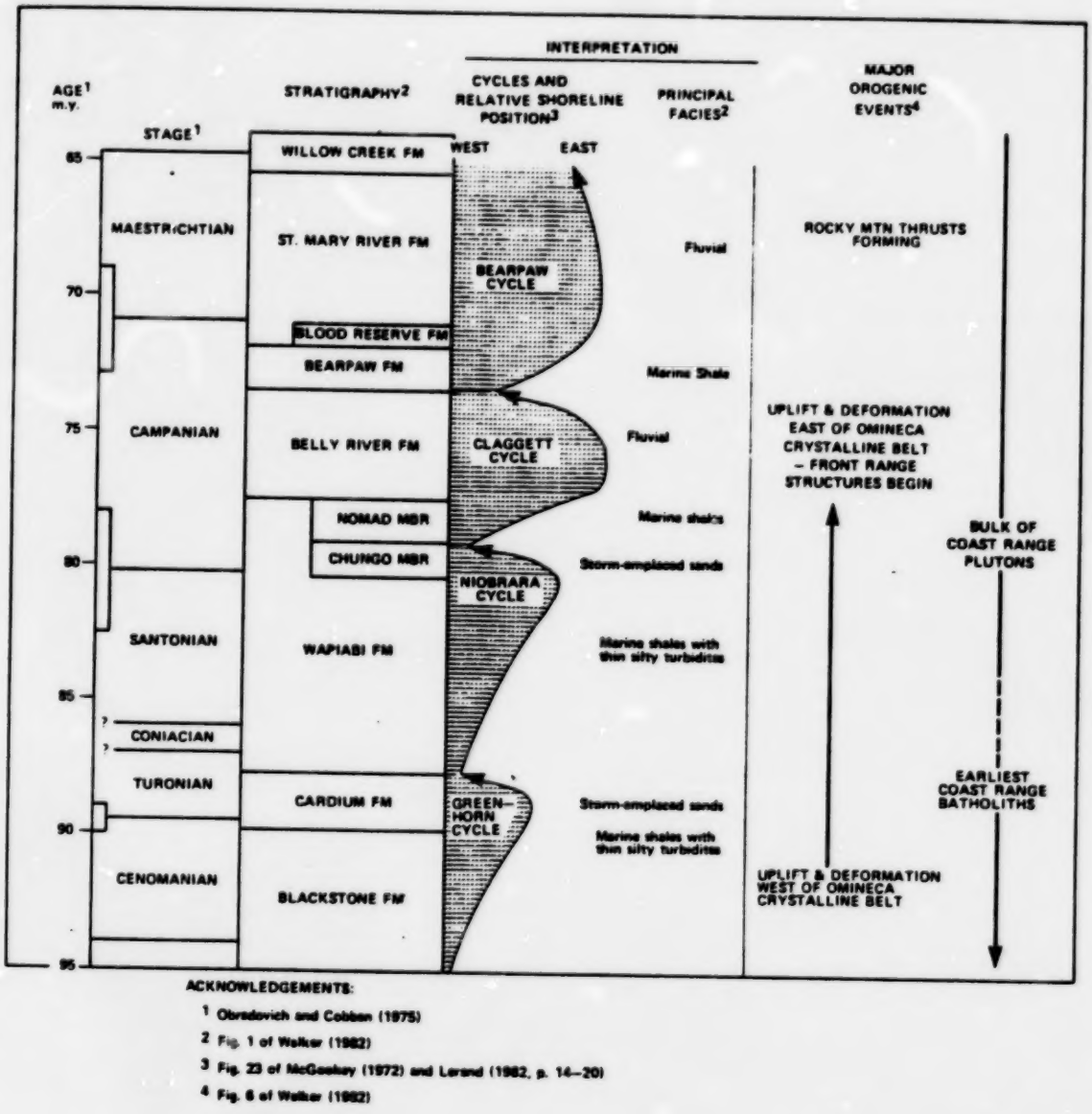


FIGURE 8. Upper Cretaceous and Paleocene stratigraphy of Alberta; synthesized from numerous sources.



ACKNOWLEDGEMENTS:

[1] Obradovich and Cobban (1975)

[2] Fig. 1 of Walker (1982)

[3] Fig. 23 of McGookey (1972) and Lerand (1982, p. 14-20)

[4] Fig. 6 of Walker (1982)

FIGURE 9. Interpretation of Upper Cretaceous stratigraphy in the Foothills region of SW Alberta. Boxed age-intervals in the first column convey uncertainty over exact chronology of stage boundaries.

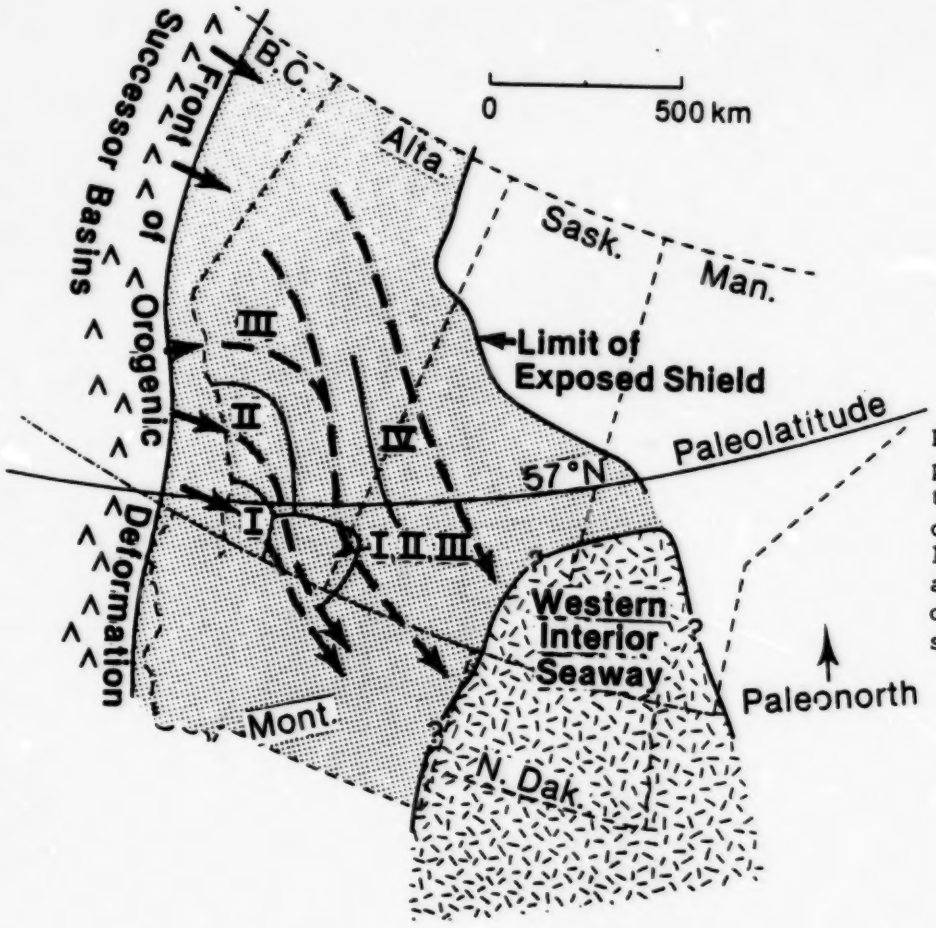


FIGURE 10. Mid-Campanian paleogeography. Arrows from the hinterland are drainage outlets (Eisbacher et al., 1974). I-IV from Rahmani and Lerbekmo's (1975) study of distinctive heavy-mineral suites.

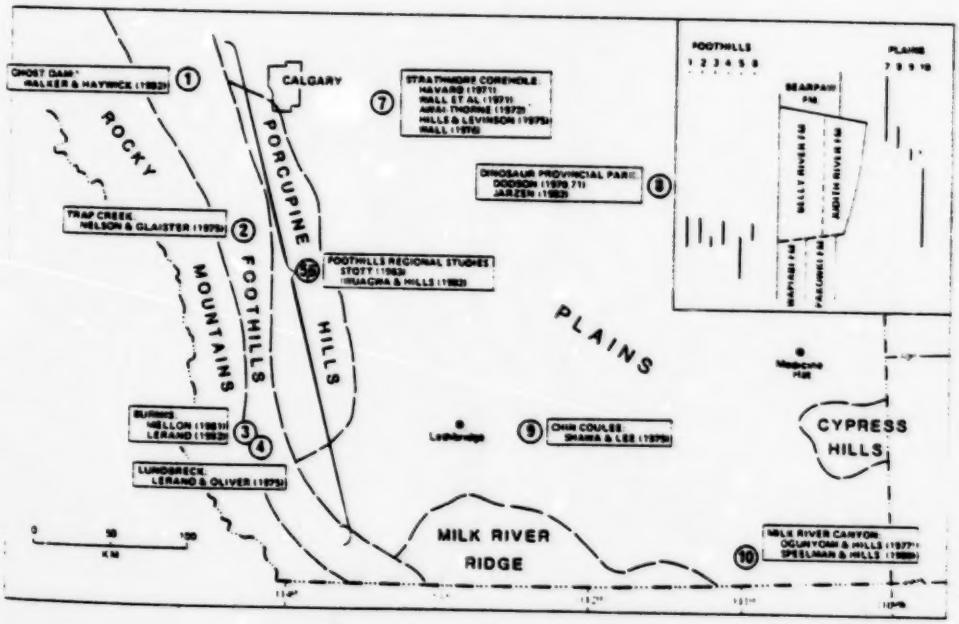


FIGURE 11. Locations of key post-1960 facies-related research with respect to the physiographic regions of southern Alberta. Inset shows the stratigraphic coverage of these studies with respect to Belly/Judith River Formation limits.

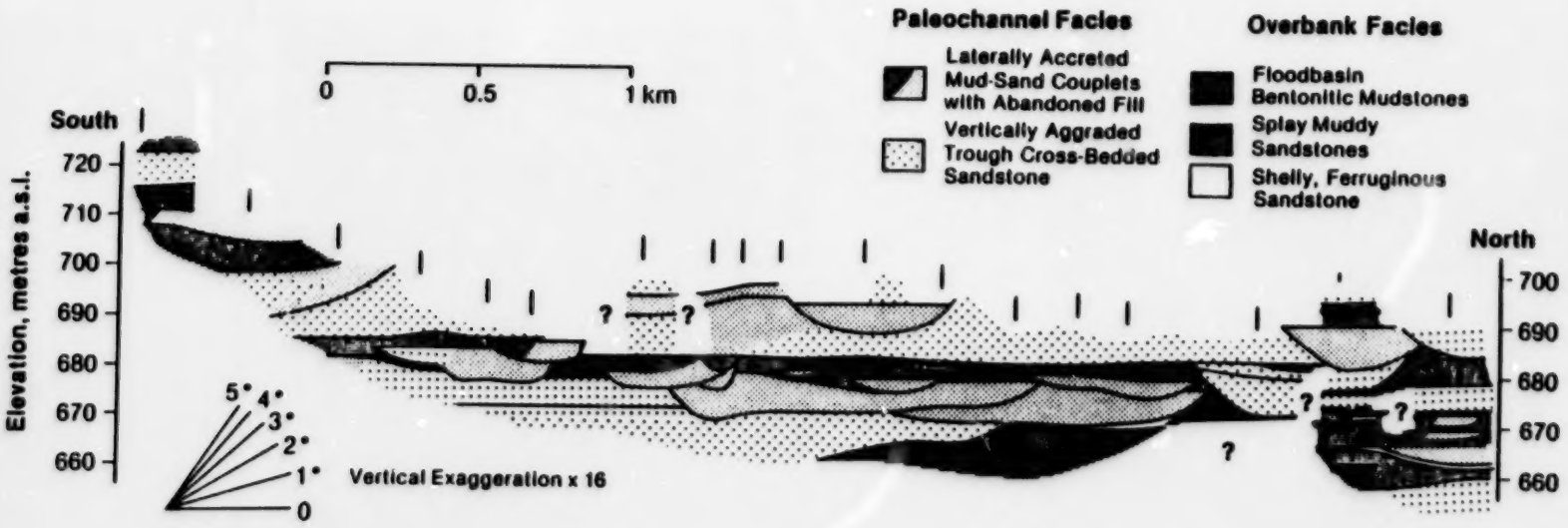


FIGURE 12. Geometry of principal architectural elements along the 464000mE traverse commencing at the southern prairie edge to local badlands.

FIGURE 13. Exposure beneath prairie level at 5628920mN, 456020mE (basal evelation ca. 676m a.s.l.) to demonstrate the geomorphic expression of alternating fine- and coarse-members in the coastal plain sequence. Note also the variability in paleochannel facies and their multistorey nature in the main cliff section.

FIGURE 14. Example of upward-fining sand-mud couplets in a Type I paleochannel sequence at 5629500mN, 456000mE (678m a.s.l.). This is a single-storey unit 9.3m thick and inclined at 11° towards 207°.

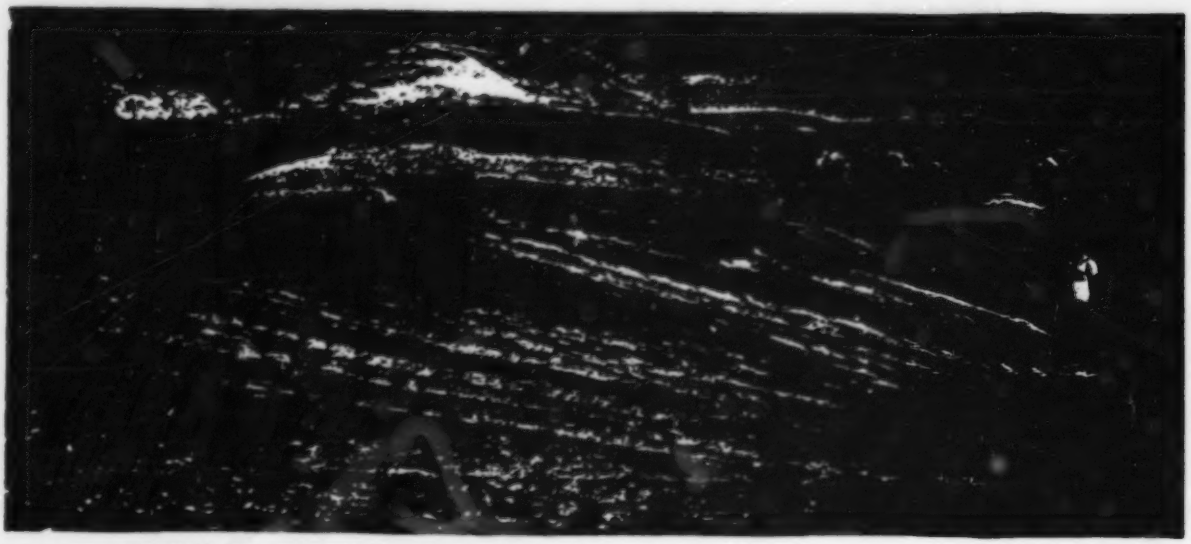


FIGURE 15. Upslope intercalation of sand-mud couplets in an upward-fining Type I paleochannel unit at 5627450mN, 455020mE (688m a.s.l.). This unit is 2.2m thick and dips at 12° towards 044°.

FIGURE 16. A Type I paleochannel unit at 5621220mN, 460080mE (704m a.s.l.) showing an unusually high degree of internal erosion surfaces. Maximum dip is 12° towards 155°; the unit is 3.9m thick.

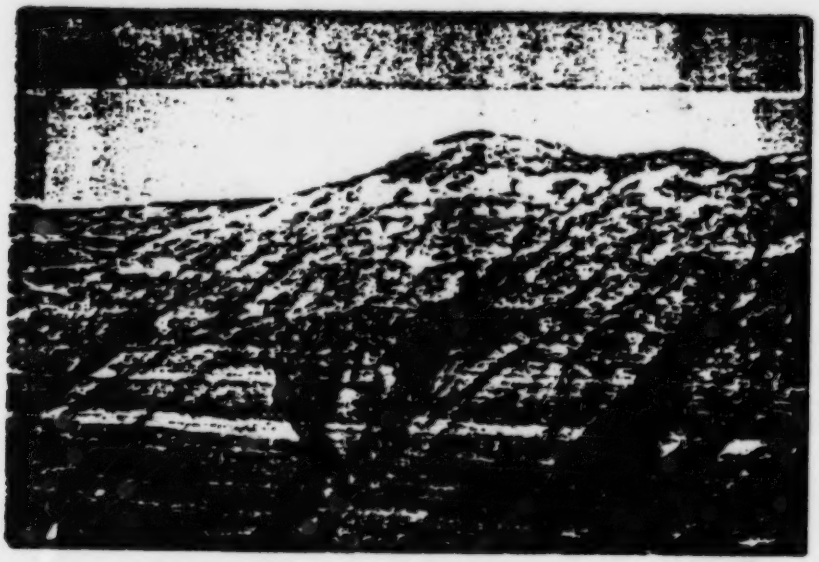


FIGURE 17. Thick zone of ball-and-pillow structures at the top of a Type I paleochannel unit seen in strike-parallel orientation; 5629050mN, 459880mE with elevation 696m a.s.l.

FIGURE 18. View of a ca. 18m thick point bar sequence which apparently correlates with the unit illustrated by Figure 14. Located at 5629500mN, 455600mE where prairie elevation is 698m a.s.l., this sequence dips westward and displays good upward-fining from a sand-dominated basal part, through sloping ironstones and sand-mud couplets, to the overlying mudstone.

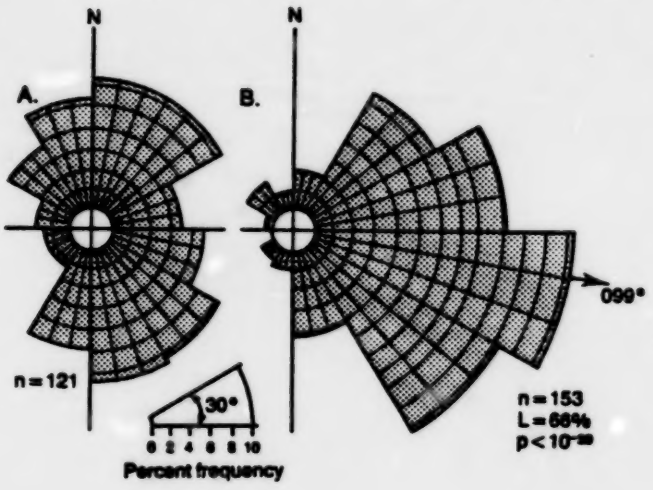


FIGURE 19. Summary rose diagrams for paleocurrent data. A) Dip directions of inclined heterolithic stratification. B) Vectorial analysis of trough cross-bed sets, using the method of Curray (1956).

FIGURE 20. Eastward view into the central thick portion of a Type II paleochannel unit, consisting entirely of large trough cross-beds. Axial plunges of all trough sets point eastward with high vector magnitude. Located at 5620200mN, 460110mE, with basal elevation of unit at 686m a.s.l.

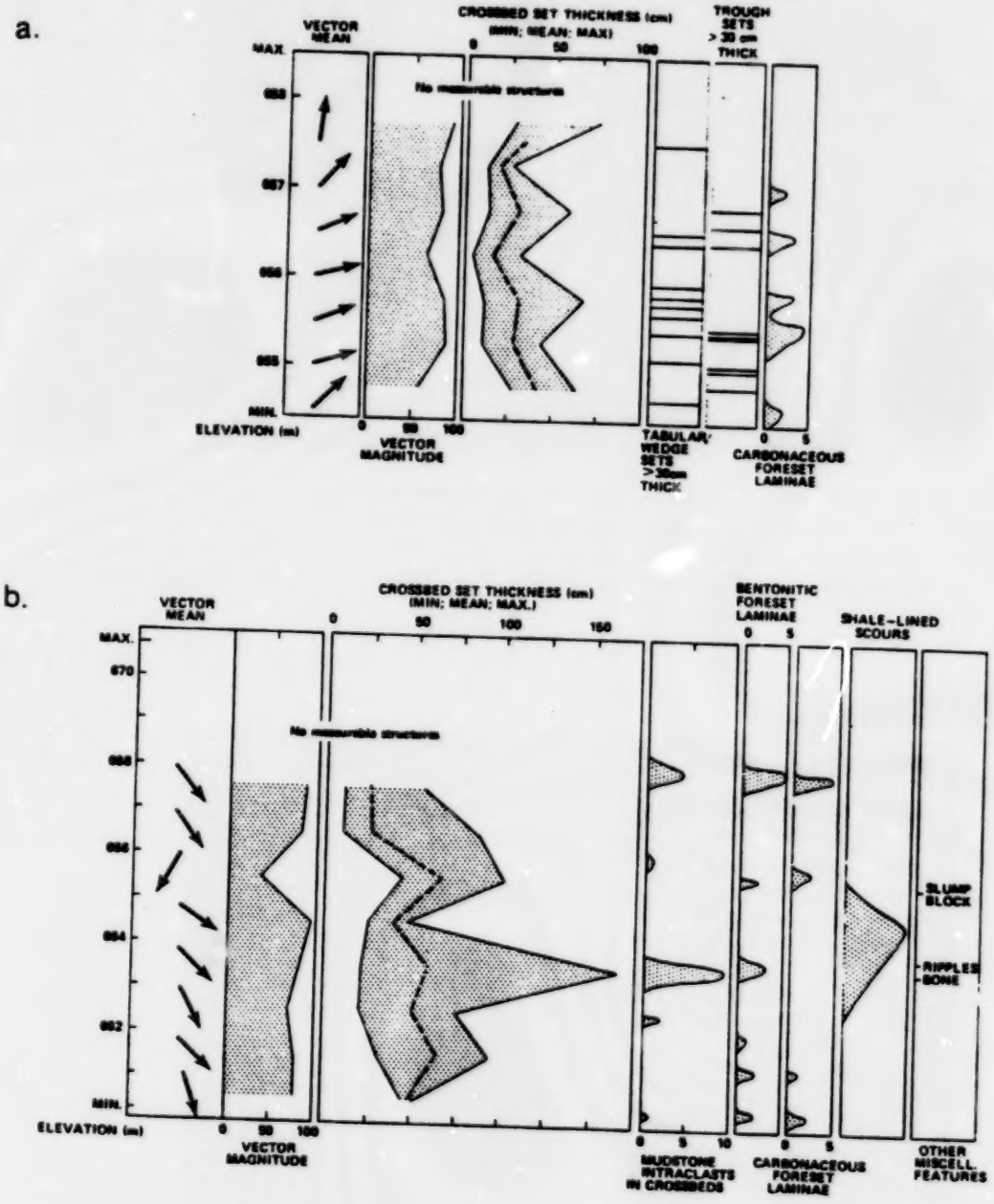


FIGURE 21. Composite vertical profiles of two single-storey Type II paleochannel sequences well exposed on the south side of the Park entrance road between 650-670m a.s.l.; 5622800mN, 463310mE.

FIGURE 22. Large asymmetric trough scour fill, 1.8m thick, at the mid-level of a Type II paleochannel sequence (person at lower right). Lower foreset and bottomset beds are outlined by bundled laminae of carbonaceous mud. Overall, the scour infill structure is virtually perpendicular to the vector mean of adjacent smaller cross-bed sets. Located at 5621620mN, 500200mE with elevation of 677m a.s.l.

FIGURE 23. Lateral view of a trough cross-bed set with paleoflow to left. Foreset structure is outlined by regularly-spaced mm-thick mud drapes each separating ca. 2cm of sandstone.

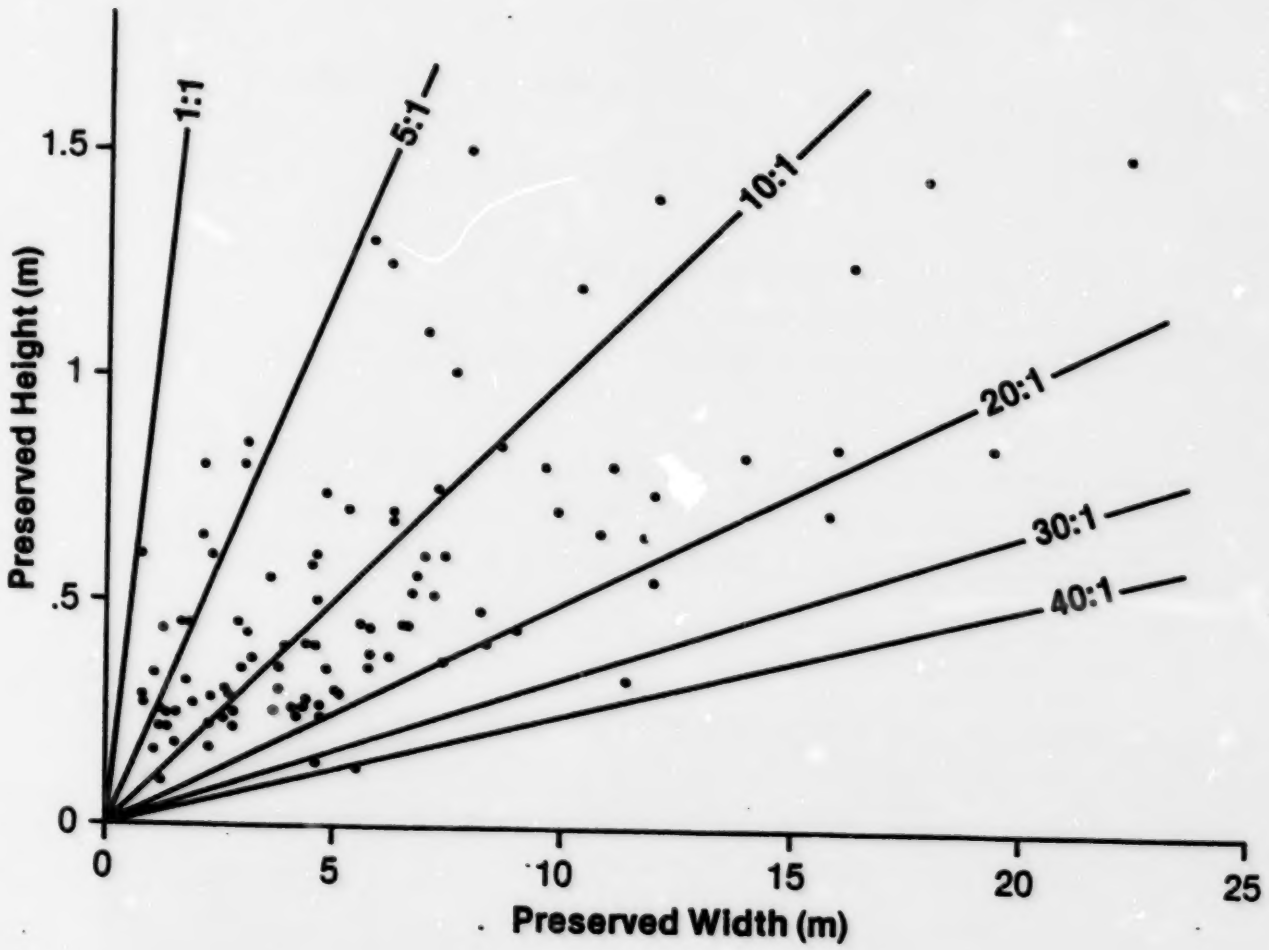


FIGURE 24. Relationship between preserved height and width of trough-producing bedforms in paleochannel sequences. Set dimensions were reliably determined from pediment exposures.

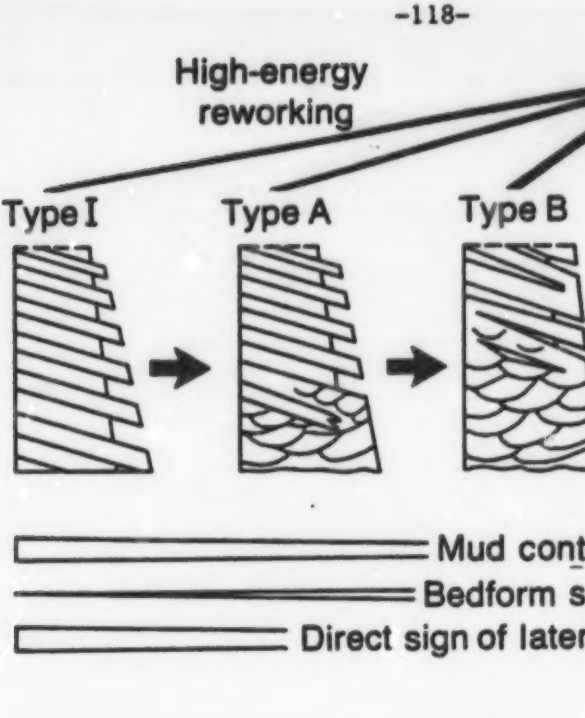


FIGURE 25. Observed spectrum of pale
en-member Types I and II. The two se
sections convey observations and inte

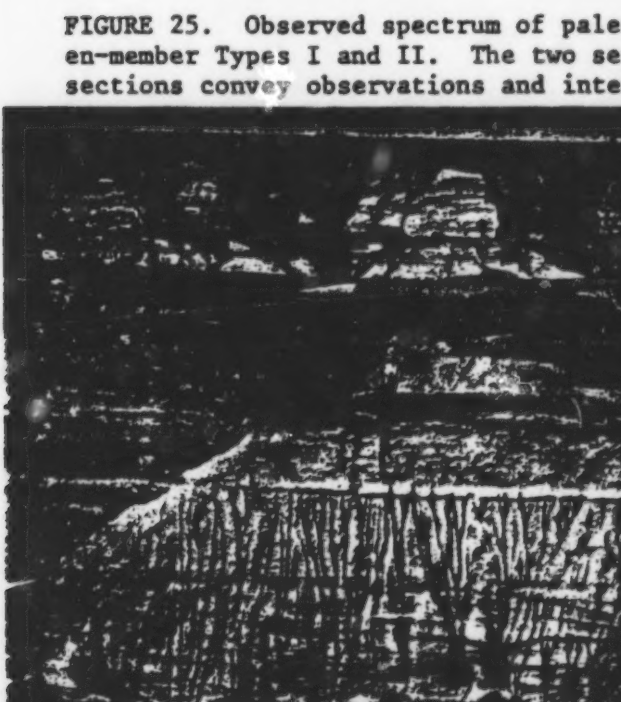
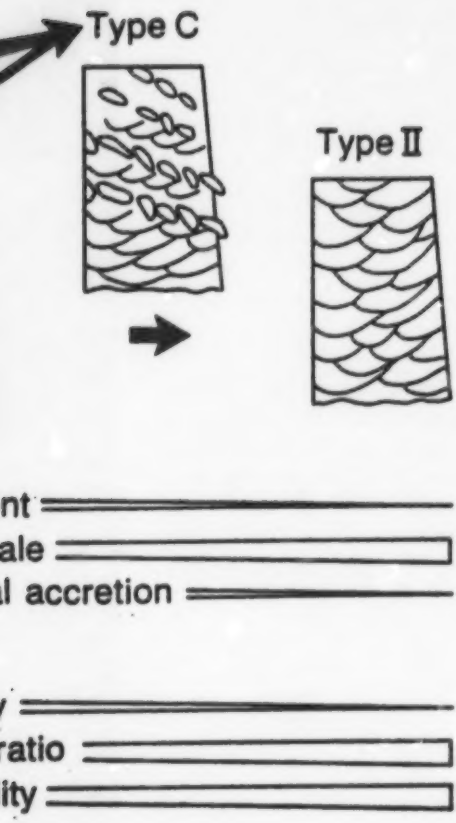


FIGURE 26. Northward view across the
along the 460000mE traverse; taken wi
in the foreground displays amalgamati



channel sequence between
s of trends below the schematic
pretations, respectively.

coulee of Little Sandhill Creek
h a 200mm lens. The coarse member
n from Type I below to Type II above.

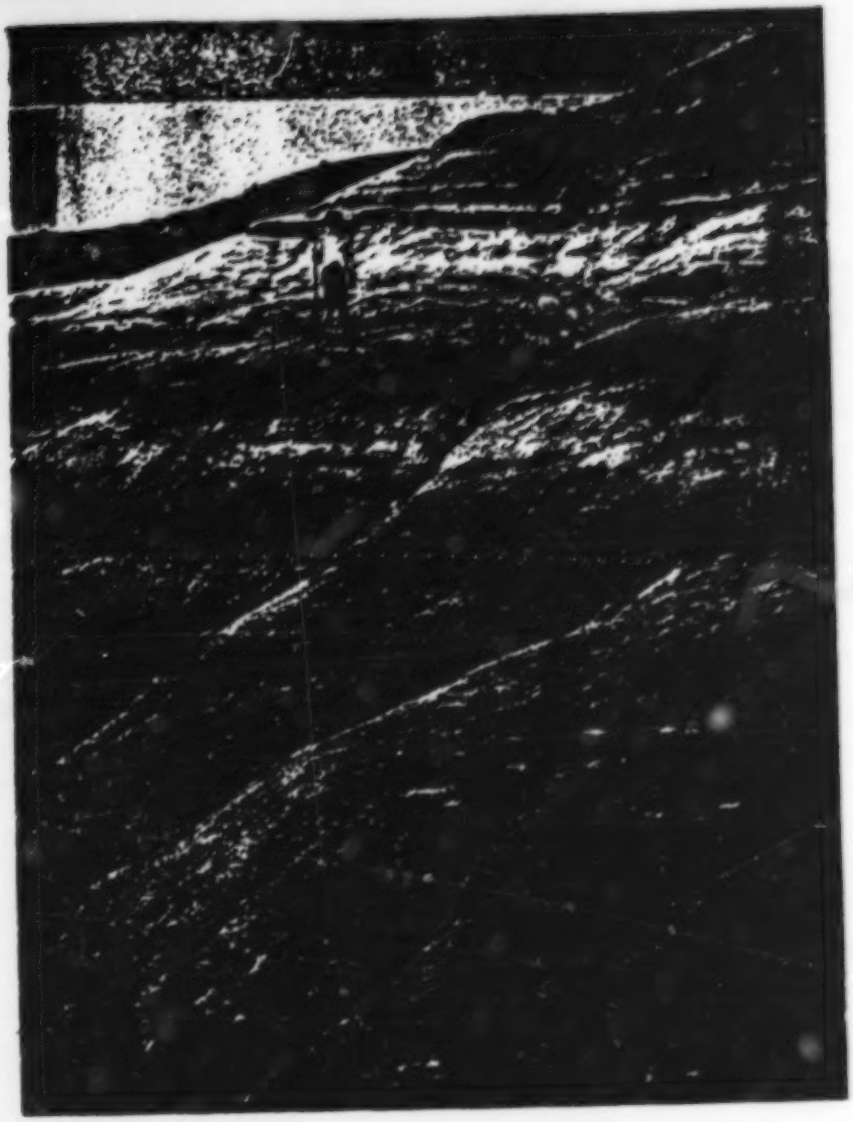


FIGURE 27. Inter-channel sequence of variegated mudstones with minor splay and volcanic ash events. Located at 5626740mN, 455150mE with elevation range from 686-697m a.s.l.

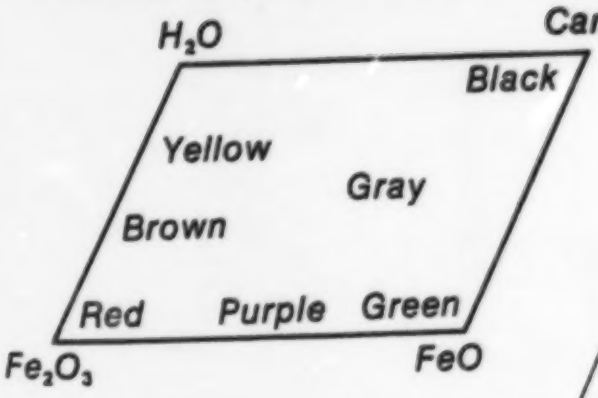


FIGURE 28. Chemical constituents influencing the colour of mudstones (Blatt et al., 1980).

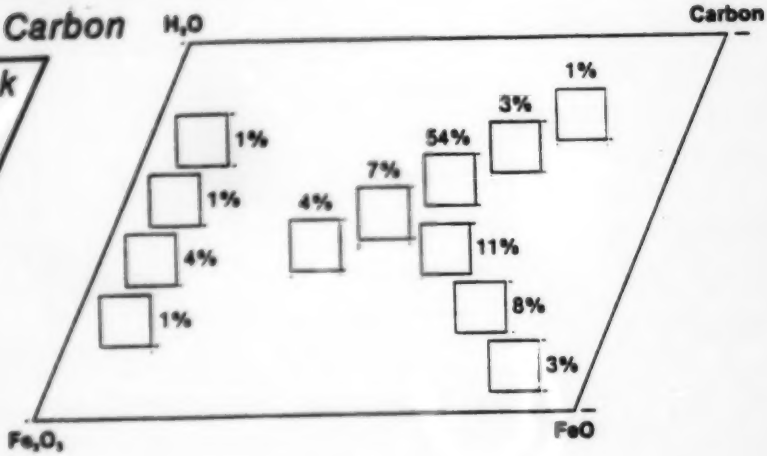


FIGURE 29. Distribution of 70 mudstone samples from Dinosaur Park classified according to the GSA rock-colour chart; three trends are evident.

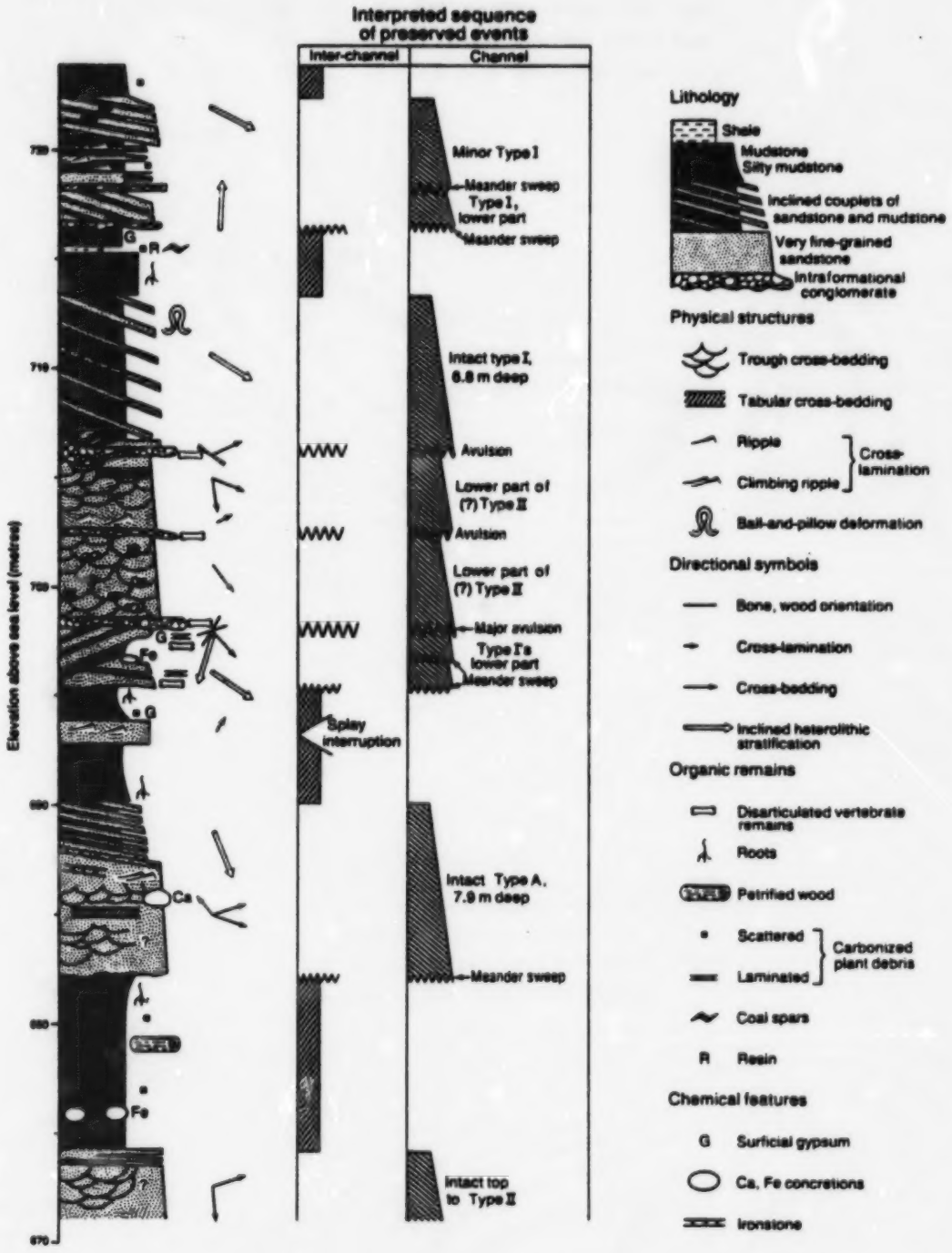


FIGURE 30. A 52m thick section at 5621430mN, 684550mE just outside the southeast boundary of the Park to show a typical degree of alternation of paleochannel (both single and multistorey) and inter-channel units.

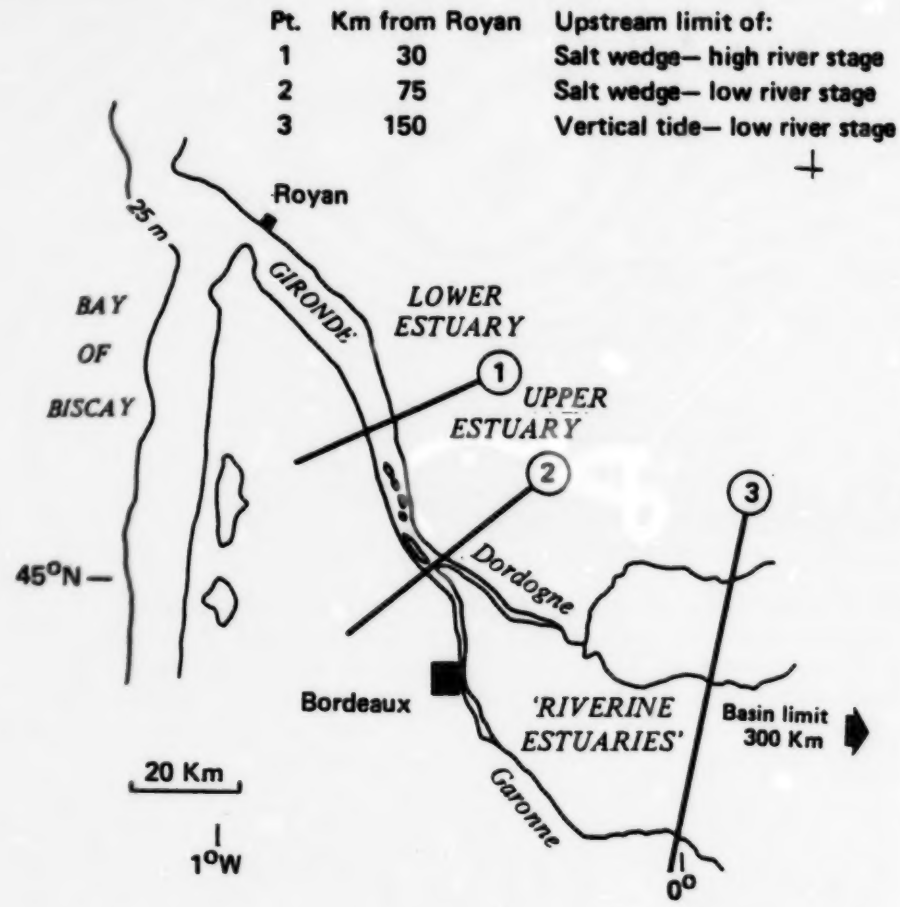


FIGURE 31. From Jouanneau and Latouche (1981) to show upstream limits of saltwater and tidal circulation in the Gironde estuary of western France.

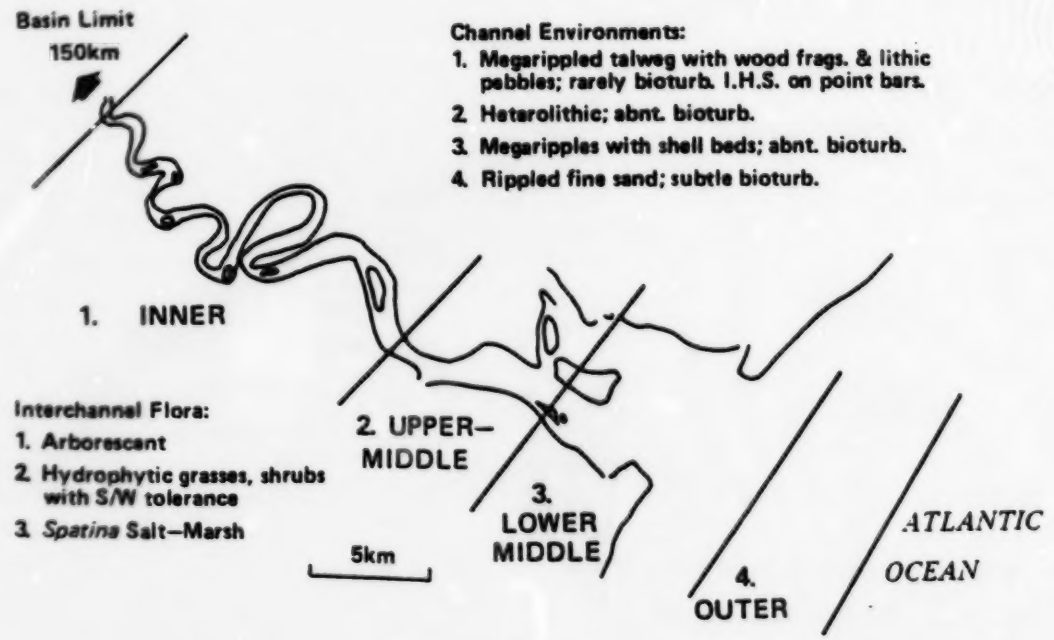


FIGURE 32. From Frey et al. (1975) to show the zonation and associated channel facies and inter-channel flora of the estuary to the Ogeechee River in Georgia.

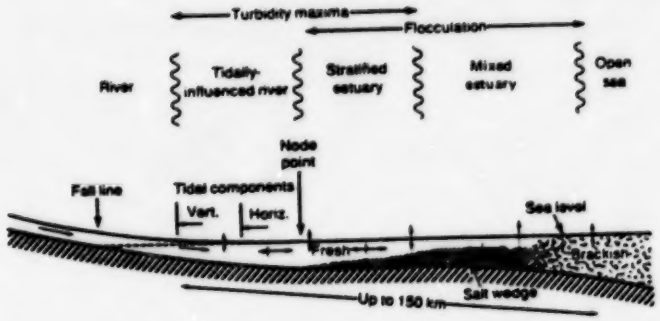


FIGURE 33. Schematic longitudinal section down a coastal plain estuary to show important aspects of water circulation and the dynamic series of zones. Each zone is characterised by a different balance of fresh and saltwater effects. Synthesised from numerous sources.

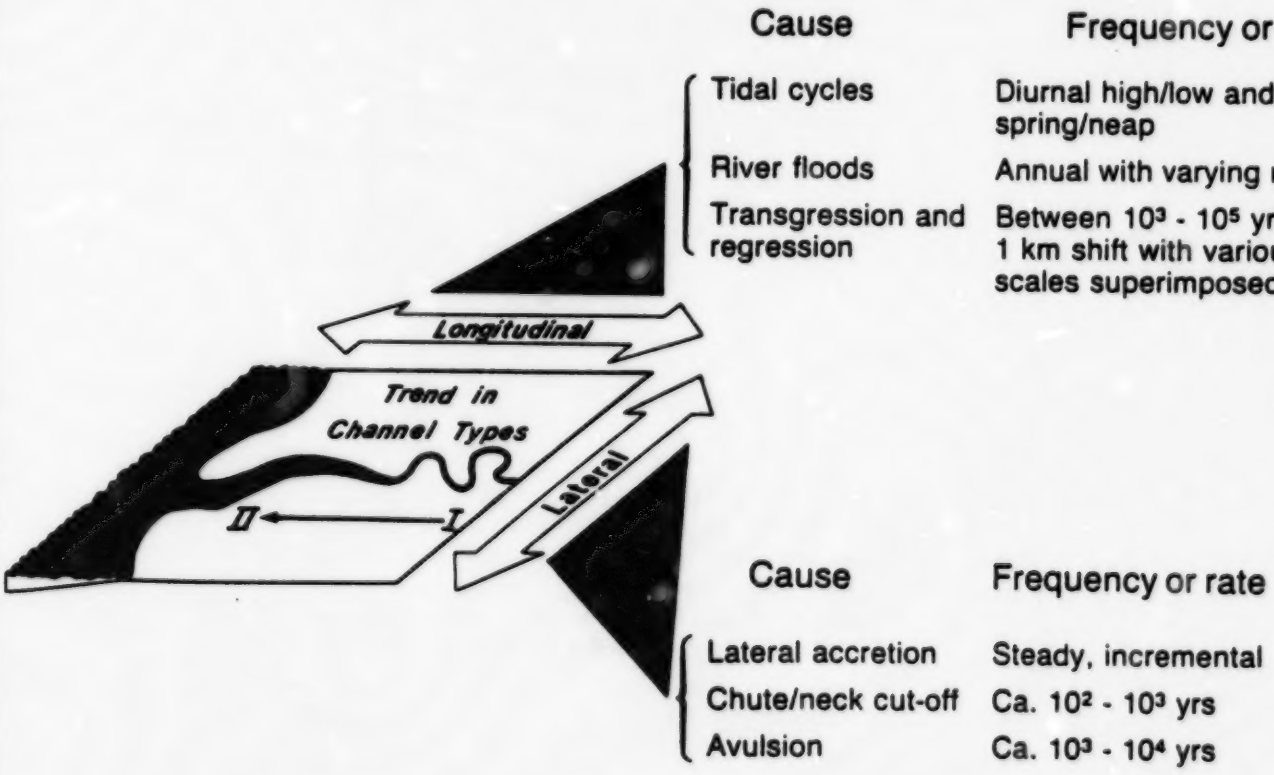


FIGURE 34. Nature and cause of shifts in estuarine subenvironments.

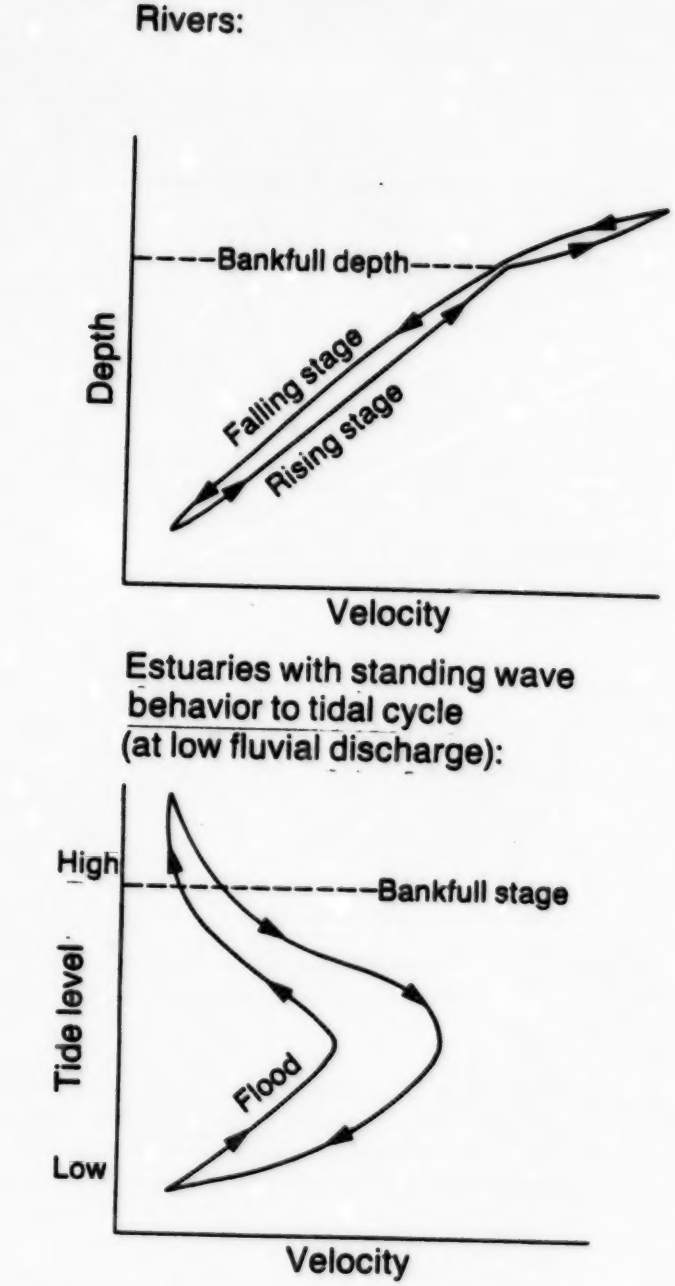


FIGURE 35. Contrasts in at-a-station hydraulic geometry between a perennial meandering river and a tidally-influenced, upper meandering reach of a coastal plain estuary. The latter setting is envisaged as the controlling hydrologic regime of Type I paleochannels (cf. Figure 34).

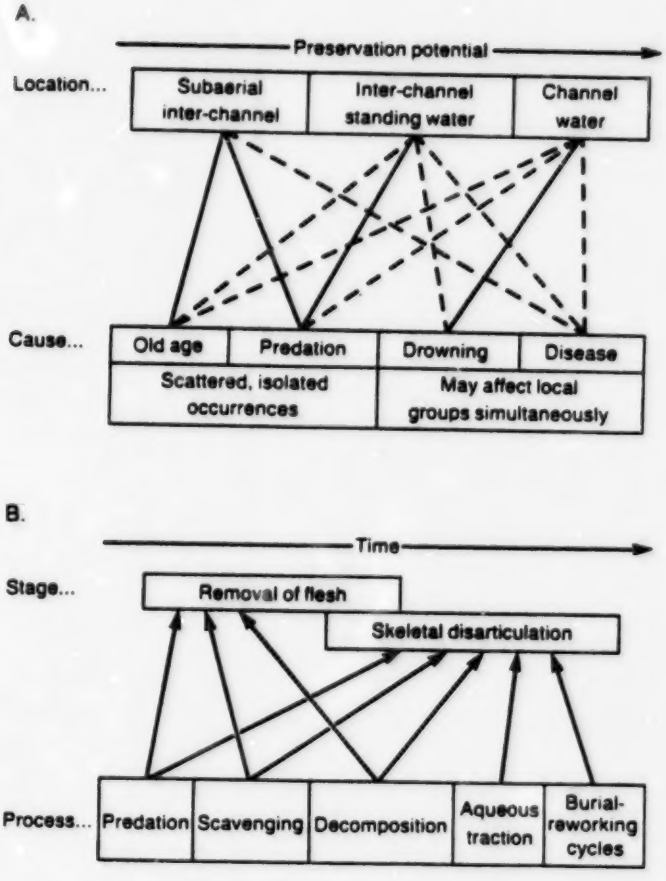


FIGURE 36. Considerations of vertebrate taphonomy (Koster, 1987). A) Proposed association between the location and cause of mortality. B) Proposed classification of processes of carcass destruction.

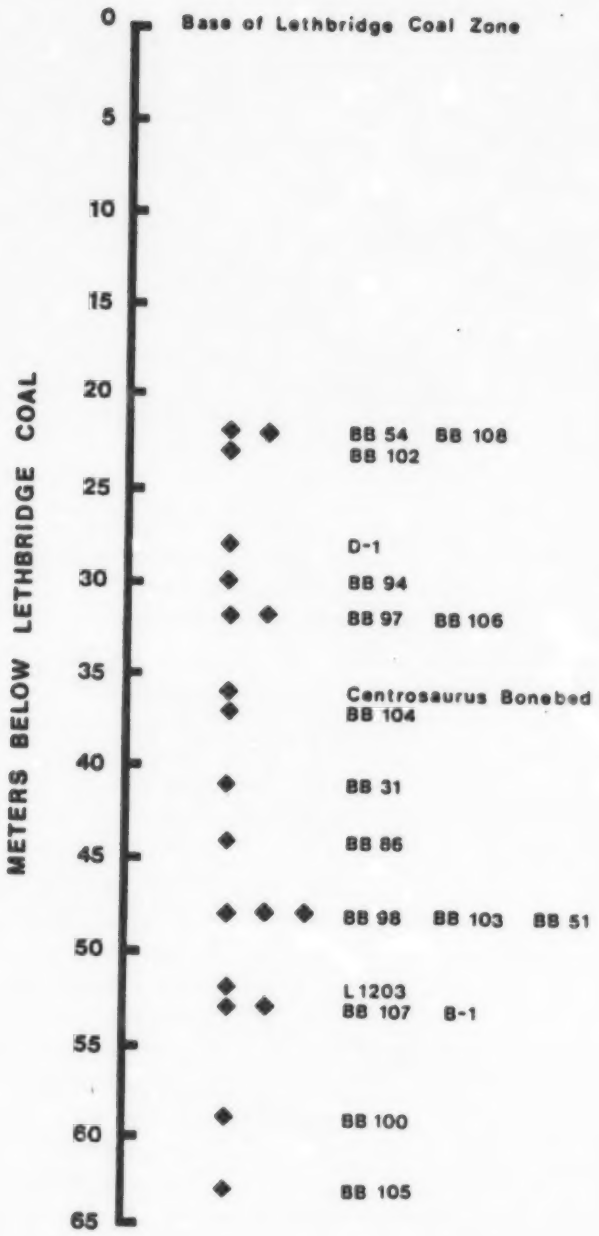


FIGURE 37. Stratigraphic positions of microvertebrate sites in the Park area badlands relatitive to the base of the Lethbridge Coal Zone. The Centrosaurus bonebed and invertebrate locality L1203 are localities discussed in Sections 5.2 and 5.4, respectively.

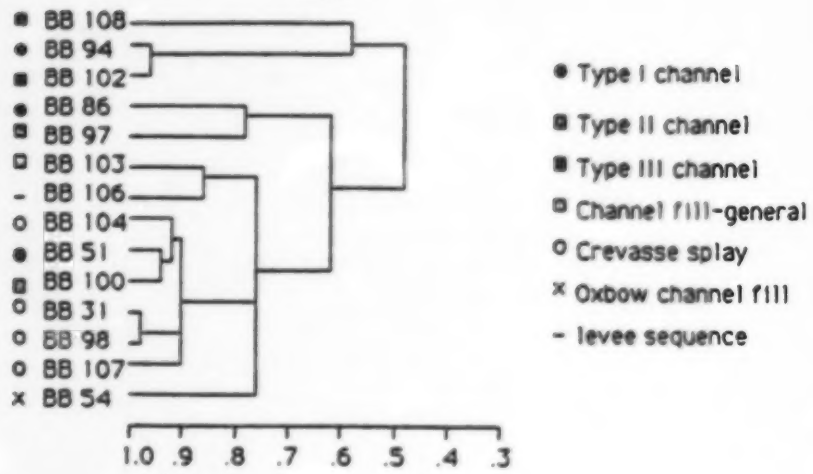


FIGURE 38. Cluster analysis based on similarities in microvertebrate assemblages relative to their sedimentological associations.

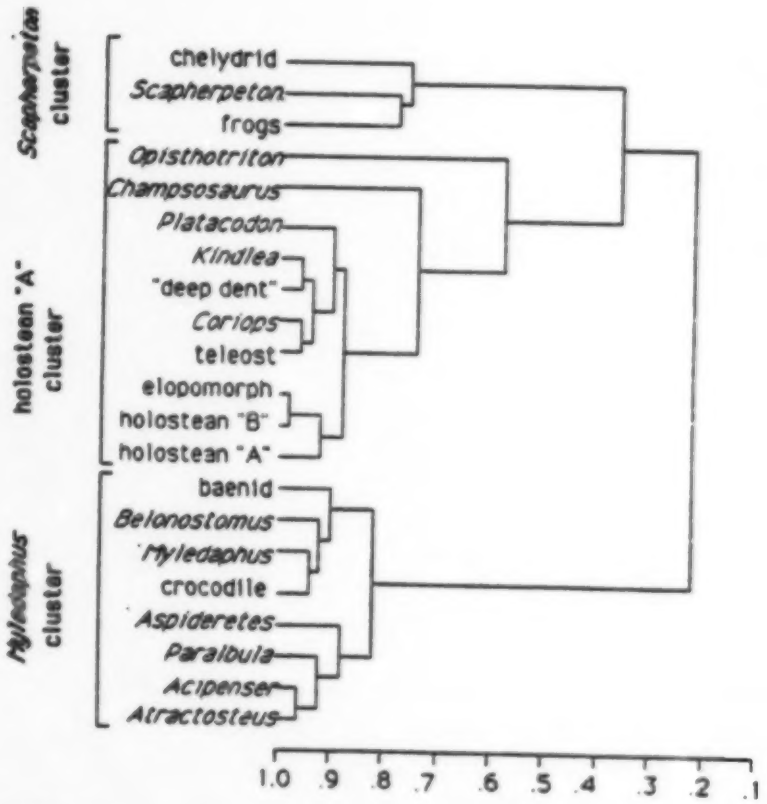


FIGURE 39. Cluster analysis of aquatic animals from microvertebrate localities showing groups that tended to co-exist.

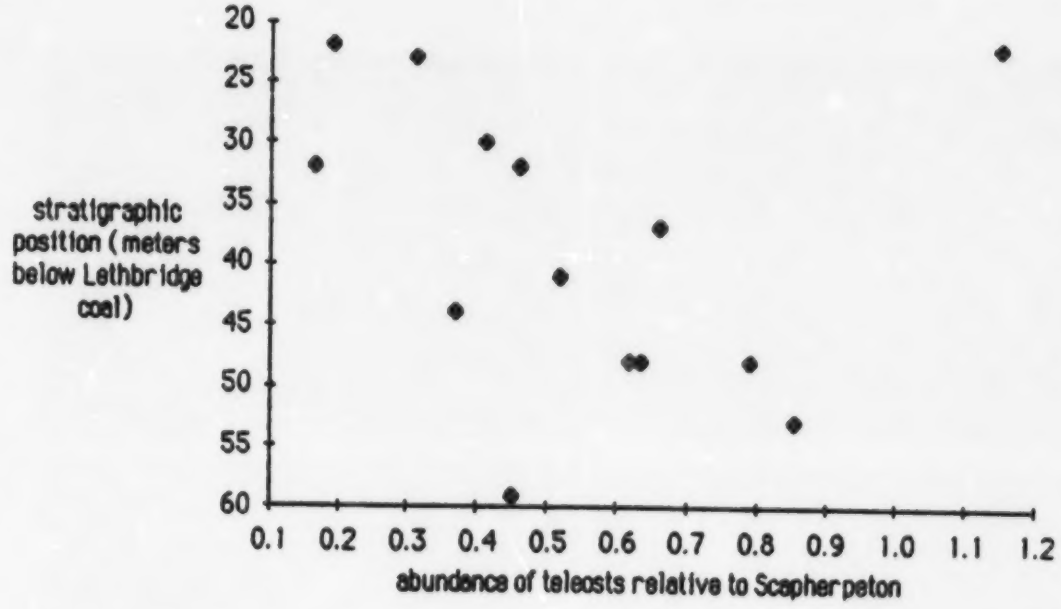


FIGURE 40. Bivariate analysis of change in abundance of teleost fish relative to salamanders according to stratigraphic position.

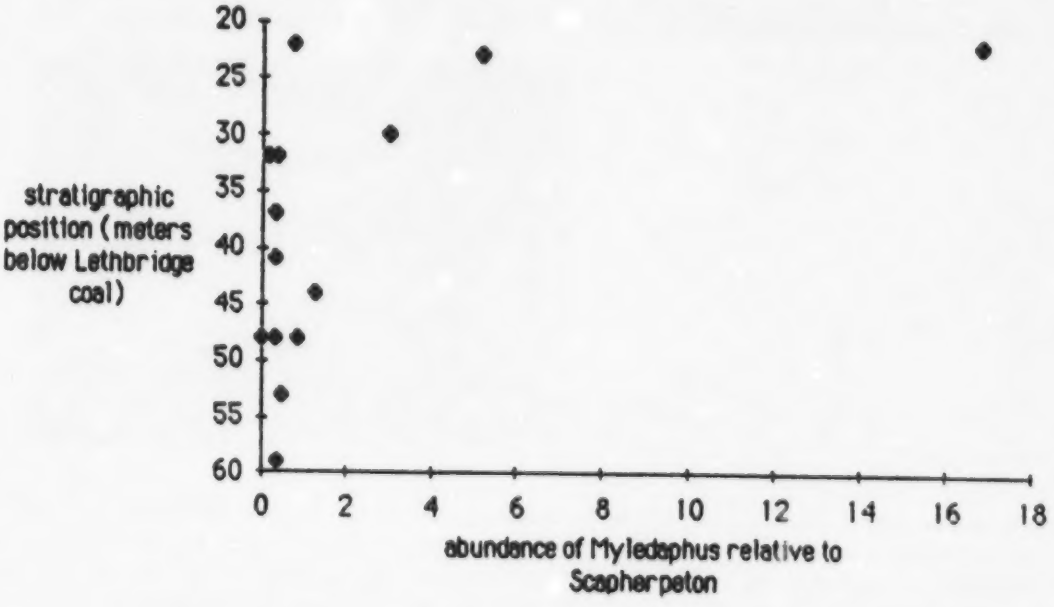


FIGURE 41. Bivariate analysis of change in abundance of Myledaphus relative to salamanders according to stratigraphic position.

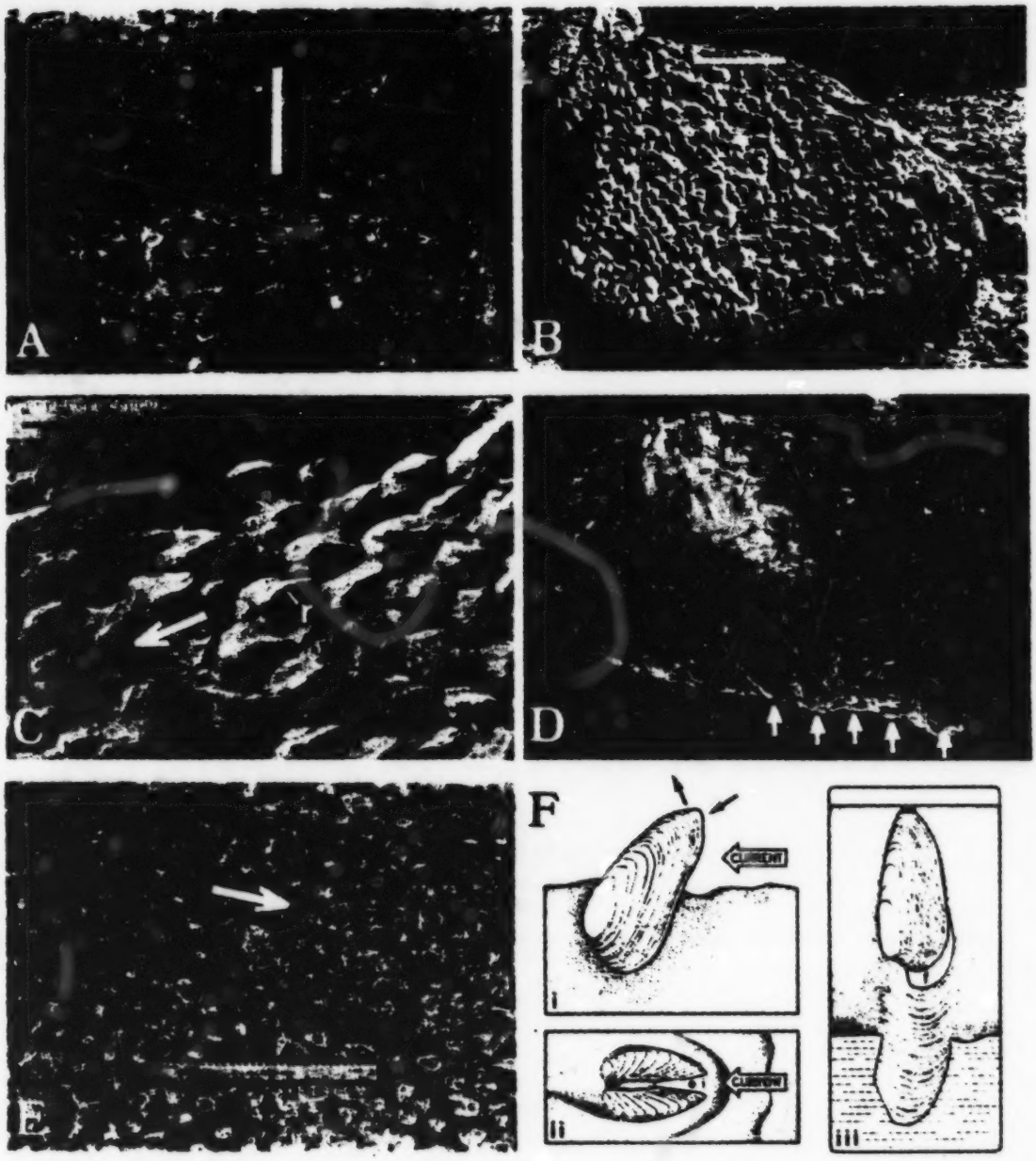


FIGURE 42. A) Slumped block showing sandstone with unionid domichnia and fungichnia overlying recessive unit with unionid shells. B and C) Overturned block with domichnia: r denotes ridge at base of domichnion produced by downward thrust of foot, and arrow indicates inferred paleocurrent direction. D) Detail of sandstone in A) with arrows indicating lower end of fugichnia: note meniscate laminae. E) Weathered surface of sandstone in A) showing cross-sections of fugichnia: arrow indicates inferred paleocurrent direction. Fi) Inferred life habit of Fusconaia? danae (Meek and Hayden) in lateral view: black arrows indicate inhalent and exhalent currents. Fii) Same as i) in plan view: e and i denote exhalent and inhalent currents. Fiii) F.? danae escaping upward through inundating sediment.

10.0 APPENDICES

10.1 Area Map Coverage

TOPOGRAPHY

Surveys and Mapping Branch, Canada Department of Energy, Mines and Resources -
1:250,000 NTS Sheet 72L, Medicine Hat (1967)
1:50,000 NTS Sheets 72L/11, Jenner (1975)
72L/12, Brooks (1975)
72L/13, Wardlow (1975)
72L/14, Halsbury (1975)

Parks Division, Alberta Recreation and Parks -
1:10,000 Dinosaur Provincial Park and Area (1979)
2m contour interval

Sheet 1	5615000-5618500mN;	467000-473000mE
2	5615000-5618500mN;	460000-467000mE
3	5621500-5627000mN;	454400-458500mE
4	5618500-5627000mN;	459000-467000mE
5	5618500-5626300mN;	467000-475500mE
6	5627000-5629700mN;	464200-467400mE
7	5627000-5633100mN;	454400-461300mE

BEDROCK GEOLOGY

Mines and Geology, Branch, Canada Department of Mines and Resources -
1:253,440 (1 inch to 4 miles) Map 695A, Brooks (1942) with descriptive notes; geology by J.S. Stewart.

Geological Survey of Canada, Department of Energy, Mines and Resources -
1:253,000(1 inch to 4 miles) Map 21-1967, Medicine Hat (1968) with descriptive notes, geology by E.J.W. Irish.
1:500,000 Map 1286A, Southern Plains of Alberta (1971) with descriptive notes; geology by E.J.W. Irish.

SURFICIAL GEOLOGY

Alberta Research Council, Edmonton -
1:250,000 NTS 72L, Medicine Hat (1972) with descriptive notes; geology by T.E. Berg and R.A. McPherson.

BEDROCK TOPOGRAPHY

Geological Survey of Canada, Department of Energy, Mines and Resources -
1:1,267,000 (1 inch to 20 miles) Map 47-1960 to accompany GSC Paper 60-32, Buried valleys in central and southern Alberta (1961), geology by A. MacS. Stalker.

Alberta Research Council, Edmonton -
1:250,000 NTS 72L, Bedrock topography of the Medicine Hat map area (1970) with descriptive notes; geology by V.A. Carlson.

VERTEBRATE FOSSIL LOCALITIES

Geological Survey of Canada, Department of Mines and Technical Surveys - 1:31,680 (1 inch to 1/2 mile) Map 969A, Steveville/Dinosaur Provincial Park (1950), with notes on dinosaur quarries by C.M. Sternberg.

10.2 Aerial Photo Coverage

Air Photo Distribution Office, Alberta Energy and Natural Resources -

1:30,000 (B&W), AS 1658 (1978): Line 2, Nos. 185-195
Line 3, Nos. 201-208
Line 4, Nos. 213-224
Line 5, Nos. 232-243

1:10,000 (B&W), AS 1576 (1977): Line 5, Nos. 113-129
Line 6, Nos. 140-164
Line 7, Nos. 173-199
Line 8, Nos. 210-237
Line 9, Nos. 247-274
Line 10, Nos. 300-326

National Air Photo Library, Ottawa -

1:10,000 (Colour), P1107 by Machair Surveys Ltd. (1977):
MA1121, Nos. 87-106, 172-190
MA1122, Nos. 70-85, 154-176
MA1123, Nos. 32-47
MA1132, Nos. 69-74, 88-90, 151-155
MA1133, Nos. 65-71, 86-87, 135-152